Forests, health and inequalities in Scotland: a longitudinal approach

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Abstract

Increasing international evidence shows that forests may enhance mental and physical health by providing opportunities for relaxation, physical activity, social interaction and through reducing air pollution. Studies also suggest that forests may have a role in reducing socioeconomic health inequalities by weakening the links between poverty, deprivation and poor health. Knowledge surrounding the relationship between forests, health and inequalities is limited as no national studies have been carried out, and findings to date are based on cross-sectional data. This thesis addresses these research gaps by examining associations between forests, health and inequalities for the whole of Scotland over a 20-year period.

Firstly, changes in the socio-spatial distribution of forests in Scotland between 1991, 2001 and 2011 were assessed. Following this, relationships between different long-term patterns of individuals' forest access and subsequent health outcomes were examined. The influence of cumulative forest access throughout life and levels of forest access at particular life stages on later mental health were also studied. Lastly, investigations into whether changes in forest access were associated with changes in general health were carried out. In order to understand whether forests might reduce socioeconomic health inequalities, each of the empirical analyses considered differences between sociodemographic groups.

Measures of forest access in 1991, 2001 and 2011 were created in ArcGIS for all postcodes in Scotland and linked to a sample of individuals in the Scottish Longitudinal Study (SLS). The SLS contains linked census records collected in 1991, 2001 and 2011 for approximately 274,000 people (5.3% of the population). The study sample included those who had: complete data; were present in all three censuses; were aged 18+ in 1991; and lived in private residences on the Scottish mainland (n=97,658). Administrative health records from 2011 to 2016, including the prescribing of antidepressants and hospital admission data were linked to the sample members. A synthetic estimation of forest use based on SLS members' characteristics and forest user information in the Scottish People and Nature Survey (SPANS) was also used to examine whether visiting forests explained the associations between forests and general health. Statistical techniques included Latent Class Growth Modelling (LCGM), hybrid effects models and tests for mediation.

Over the study period, geographical access to forests improved throughout Scotland. However, there was evidence that individuals with low socioeconomic status in 1991 were more likely to have worse long-term patterns of forest access than those with higher

socioeconomic status. There was evidence that these worse trajectories of forest access had implications for later health; individuals with better forest access trajectories had reduced risk of having worse health at the end of the study period. Women with a greater accumulation of forest access were less likely to attend a mental health outpatient clinic or be prescribed antidepressants during 2011-2016. For men and those without qualifications who had improved forest access between time points, the risk of having a long-term illness reduced, compared to those whose forest access did not change. Findings also suggested that better forest access across the life course and at particular stages in adulthood may be linked to reduced inequalities in mental health between men and women and between those with higher and lower socioeconomic status. Forest use partially explained the association between forest access and general health but there was also evidence of a direct effect of forest access on mental health.

The key contribution of this thesis was the linkage of spatial environmental data to census and administrative health records for individuals and the application of a longitudinal approach. The thesis also contributes to the international literature by providing new insights into the causal mechanisms though which forests may influence health across the life course and how these may vary between social groups. The research has provided important evidence for policy makers such as Forestry Commission Scotland, about the social value of forestry in Scotland (and potentially elsewhere) and the opportunities that maintaining and enhancing forest access could have for improving population-level mental health and reducing health inequalities. In particular, those designing interventions to encourage forest use among disadvantaged groups should consider how interventions could be targeted at those with low individual-level socioeconomic status as well as deprived areas. Future research should use life course approaches to better specify the ways in which forests may support health for those with specific mental illnesses, and where possible consider the effect of forest access in childhood as well as adulthood on later life health outcomes.

Lay Summary

Studies from across the world suggest that forests are linked to better health by providing attractive places for people to exercise, relax and take part in social activities. It has also been shown that the health-promoting effects of green spaces are greater for those living in poorer neighbourhoods. Therefore, forests which are in close reach of deprived communities could have a role in reducing the health gap between richer and poorer groups. However, knowledge about the links between forests and health is limited as research to date has been based on information collected at one point in time. Being able to follow the same people through time, and record information about their level of forest access and health at different time points would provide a better indication of whether the influence of forests on health is causal. This thesis explores changes in public access to forests, and the relationship between forests and health through time by investigating the following questions:

- Do people with better long-term patterns of forest access have better health?
- Are there certain stages in a person's life when forests have a greater effect on later mental health or do protective effects of forests on health build up over time?
- Does people's general health improve when they live closer to forests?
- Does visiting forests explain improvements in health?
- Is the influence of forests on health stronger for particular social groups?

This research took place in Scotland and was the first study to explore the links between forests and health through time, on a national scale. It involved the collection of digital maps which showed the locations of all forests and residential postcodes in 1991, 2001 and 2011 and enabled levels of forest access to be estimated. The distance from each postcode to the nearest forest was calculated for the three time points. These were then linked to the Scottish Longitudinal Study (SLS) which contains census information for 5% of the population in 1991, 2001 and 2011. Further health records during 2011-2016 were also linked to the final study sample of 97,658 people which indicated mental health problems such as depression. Statistical tests were applied in order to identify potential relationships between people's forest access and their health. Tests were also run separately for men and women, by age group and level of education.

For the whole of Scotland, people's level of forest access improved between 1991, 2001 and 2011. However, people who were worse-off had poorer forest access throughout the study period than those who were more advantaged. Those with better patterns of forest access

over time also had better health during 2011-2016. The influence of forests on health varied between men and women. For example, men who had improved forest access between time points had better general health than men who did not experience improvements in forest access. For women, protective effects of forests built up over time and reduced the risk of mental health problems later in life. The findings also indicated that better levels of forest access throughout life and at particular stages in adulthood may help to narrow the gap in health between men and women; and between worse-off and more advantaged individuals. Visiting forests provided some but not all of the explanation for the relationship between forests and general health. This suggests that forests also enhance people's health without necessarily having to visit e.g. through feeling less stressed when viewing forests from a window.

By using information about people's forest access and health collected at different time points over a 20-year period, this study has enhanced what we know about relationships between forests and health; and how relationships might be stronger or weaker for particular groups of individuals. The research findings also have some important policy messages, particularly for organisations like Forestry Commission Scotland. For example, initiatives aimed at improving the health of disadvantaged groups may consider the ways in which those who are worse-off may be encouraged to visit forests, as well as improving levels of forest access in deprived neighbourhoods. In order to build on this study, future research may explore the ways in which forests may help to ease symptoms of specific mental illnesses and also assess how experiences of forests in childhood may influence health later in life.

Author’s Declaration

I declare that this thesis has been composed solely by myself and that it has not been submitted, either in whole or in part, in any previous application for a degree. Except where stated otherwise by reference or acknowledgment, the work presented is entirely my own.

Some of the arguments made in Chapter 2 relating to the mechanisms through which forests may influence health; and some of the findings in Chapter 4 relating to the changes in forest access which took place in Scotland during the study period were published in the following article: Hobbs, M., Noall, J., Suckling, R., 2018, Understanding links between the environment, public health and inequalities, Town & Country Planning, 87, 7, 273-276. Hobbs and Noall each contributed a short case study about each of their PhD topics, including the policy implications of the findings presented. Suckling provided commentary on the challenges of implementing local and national strategies to address the public health issues highlighted in each case study.

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Date:

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1 Introduction

1.1 Mental health, inequalities and the physical environment

In 2018, the World Health Organization (WHO) called for immediate action to tackle non-communicable diseases including mental illnesses and long-term health conditions (World Health Organization 2018d). Globally, depression is one of the most common mental illnesses, currently affecting 300 million people, and is the leading cause of disability (World Health Organization 2018a). Depression and other mood disorders are also highly correlated with suicide (Angst et al. 1999) which accounts for 800,000 deaths worldwide each year (World Health Organization 2018a). Addressing such mental health problems is a global public health priority and is included in the United Nations' 2030 Sustainable Development Goals (Scorza et al. 2018).

In the United Kingdom (UK), it has been estimated that a quarter of the population is affected by a mental health issue each year (Mental Health UK 2018). In a recent survey of approximately 2,300 people, just under half reported that they had experienced depression and a quarter reported panic attacks (Mental Health Foundation 2017). In Scotland, the situation is worse than the UK average with one in three people affected by a mental health problem in any given year (Scottish Government 2018), and suicide rates approximately 4% higher than in England (Samaritans 2017). Compared to most other Western European countries, Scotland has a lower life expectancy, higher mortality rates and larger socioeconomic health inequalities (The Scottish Public Health Observatory 2018). The difference in healthy life expectancy between those living in the 10% most and 10% least deprived areas is 25 years for males and 22 years for females (Scottish Government 2015b). Studies investigating the causes of Scotland's poor health record and disparities between rich and poor have pointed towards the country's social, political, economic and employment history, and poor quality living environments particularly in Glasgow, which has negatively affected health behaviours (Popham 2006; Smith & Morris 1994; Walsh et al. 2016). In order to enhance health and reduce health inequalities in Scotland, a suite of policies addressing social, economic and environmental policies including those focusing on the physical environment have been recommended, one of which includes *"improving greenspace access and quality in deprived areas"* (Walsh et al., 2016, pg.10). This recommendation draws on increasing evidence of associations between access to green spaces and a range of health outcomes; and the evidence that there are smaller health inequalities between deprived and affluent areas with greater access to green spaces than areas with lesser green space access (Mitchell et al. 2015; Mitchell & Popham 2008).

1.2 **The role of forests in addressing public health challenges**

One area of growing academic and policy interest is the potential health benefits of forests. The term 'forest' can be used to describe land areas predominantly made up of trees and includes large tracts i.e. plantations, and smaller areas known as woods or woodland (Forestry Commission, 2017c). Studies in a range of contexts from across the world suggest that forests may influence aspects of both physical and mental health and enhance quality of life. It has also been suggested that forests improve health, particularly for those living in deprived areas. Therefore, forests may potentially help to reduce socioeconomic health inequalities (Bielinis et al. 2018; Nordh et al. 2009; Ward Thompson & Aspinall 2011). In Asia and Europe it has been demonstrated that visiting or viewing forests can improve mood, reduce symptoms of mental illnesses (Iwata et al. 2016; Komori et al. 2017), support recovery from surgery (Ulrich 1984) and enhance immunity (Tsao et al. 2018). It has also been demonstrated that living in areas with more forests is associated with higher abilities to cope with stress (Kühn et al. 2017). The mechanisms through which forests are related to health include stress reduction (Ulrich 1983), mental restoration (Kaplan & Kaplan 1989), improving air quality by reducing pollutants (Nowak et al. 2014) and providing opportunities for physical activity (Pietilä et al. 2015) and social interaction (O'Brien et al. 2014).

The role of forest planning and management in policies addressing many of the current public health challenges, and for meeting targets for sustainable development, has been recognised internationally (Food and Agriculture Organization of the United Nations 2018). For example, in Europe it is recommended that expanding forests in urban areas and improving forest access should be *"at the heart of local and regional spatial planning"* (European Environment Agency 2011 p.4) in order to reduce health risks, particularly those associated with urban living and climate change, and in countries with ageing populations.

Enabling access to forests for social benefit and community health and wellbeing is currently a key feature of forestry management policy in Scotland. For example, in 2005, Forestry Commission Scotland (FCS) launched the *Woods In and Around Towns (WIAT)* funding programme which enables local authorities and community groups in urban areas to improve access to, and quality of, local woodlands through physical enhancements and provides support for social engagement activities to encourage regular use of urban woodlands (Forestry Commission Scotland 2015). Furthermore, FCS have developed a Woods for Health Strategy, written in partnership with Scottish Natural Heritage (SNH) and NHS Scotland, which outlines actions for delivering the health benefits of forests to all, for example, to *"create opportunities and provide support for people living in our most deprived communities, through woodland programmes, grants and partnerships"* (Forestry Commission Scotland 2009b pg. 15). Forests have also been incorporated into the delivery of healthcare through *Branching Out*, a programme providing a 12-week course of outdoor learning activities to adults with mental health issues (Forestry Commission Scotland 2018). The *NHS Forest: Growing Forests for Health* programme has enhanced the grounds of 150 hospitals across the UK. Scottish examples include Ninewells Hospital and Medical School in Dundee; and Argyll and Bute Hospital, a specialist mental health hospital on the west coast. Interventions such as the installation of accessible trails, therapeutic gardens and green gyms have allowed patients (and hospital staff) to improve their health and wellbeing by being more physically active and partaking in outdoor therapy sessions as part of their "green prescriptions" (Centre for Sustainable Healthcare 2018; Forestry Commission Scotland 2010).

While evaluations of the above programmes and the broader international literature have found evidence to support a positive relationship between forests and health, there are still a number of methodological constraints which limit our understanding of this link. For example, most of the studies to date have been based on cross-sectional designs, focusing on small samples at one particular time point. Therefore, potential causal associations and pathways cannot be tested and the long-term effects of forest access on health cannot be explored. Furthermore, there have been no investigations into how national distributions of forests may have changed over time due to macro-level factors and how these may have exacerbated or reduced inequalities in forests across different places, contexts and sociodemographic groups.

1.3 Aims and objectives

This thesis provides new insights into the associations between forests, health and inequalities; and contributes to the international evidence base by adopting a longitudinal approach using national-level data sources. The investigation is located in Scotland and uses census and administrative records that captures people's access to forests and different health outcomes at three time points during a 20-year period. The thesis addresses the following research aims and objectives:

1. **To assess changes in the socio-spatial distribution of forests in Scotland between 1991, 2001 and 2011 (Chapter 4).**

- How has the geographical extent of and access to forests changed over this period?
- How have changes in forest access varied between: deprived and affluent neighbourhoods; different parts of Scotland; and urban and rural areas?

2. **To examine the relationship between different patterns of forest access over a 20-year period (1991-2011) and subsequent health outcomes (Chapter 5)**

- Is access to forests in 1991, 2001 and 2011 associated with general and mental health outcomes during the period 2011-2016?
- To what extent do sociodemographic characteristics of individuals predict individuals' forest access trajectories?
- Are different trajectories of forest access between 1991 and 2011 predictive of general and mental health outcomes during 2011-2016?

3. **To what extent do particular life course models of health describe associations between forest access and mental health in later life (Chapter 6)**

- At which stages of adulthood is forest access associated with mental health during 2011-2016?
- Is a greater accumulation of forest access between 1991 and 2011 associated with better mental health in 2011-2016?
- Do associations vary between different socio-demographic groups (sex, socioeconomic status, age, area-level deprivation and urban rural classification)?
- Is forest access associated with a reduction in inequalities in mental health?

4. **To investigate whether changes in forest access over time are associated with changes in general health (Chapter 7)**

- Are changes in individuals' forest access between 1991, 2001 and 2011 associated with changes in general health between time points?
- Does the above association vary between different socio-demographic groups (sex, socioeconomic status, age, area-level deprivation and urban rural classification)?
- Does use of forests explain the association between forest access and general health?

1.4 **Thesis structure**

The thesis consists of eight chapters. Chapter 2 includes a review of the current empirical evidence and theoretical perspectives regarding associations between forests, health and inequalities, and discusses the ways in which the thesis aims to contribute to and advance this knowledge. These discussions draw on broader theoretical understandings of place and health, including socioecological models and the environmental justice framework. Chapter 3 describes the data sources and measures used in the analyses. These include a large representative sample of individuals from the Scottish Longitudinal Study (SLS), which contains census data from 1991, 2001 and 2011; linked administrative health records; and data from historical forest inventories. Methodological approaches such as the linkage of forest access measures and synthetic estimations of forest use are also described. The particular statistical techniques applied, and results of the analyses are explained in each of the following four empirical chapters. As outlined above, Chapter 4 consists of an area-level analysis exploring changes in levels of forest access for the population of Scotland between 1991, 2001 and 2011. Chapter 5 then explores different trajectories of forest access for a sample of individuals in the SLS and examines associations between forest access trajectories, sociodemographic characteristics and different health outcomes at the end of the study period. Chapter 6 further investigates relationships between forests and mental health through time by using life course models of health. Then, in the final empirical chapter, the analysis explores changes in forest access and changes in general health and whether people's use of forests explains the association between forests and health. Lastly, Chapter 8 discusses the key findings and reflects on the strengths and weaknesses of the study. The thesis then concludes by summarising the main contributions to knowledge and implications for policy.

2 Background

2.1 Place, nature and health

Over recent decades, there has been a growing interest in how place matters for people's physical and mental health. This is supported by a large evidence base which proposes that structures and contextual features of residential, work and recreational environments e.g. housing conditions, social capital and air quality (Macintyre et al. 2002) may be 'salutogenic' i.e. promote health, or 'pathogenic' i.e. impair health (Antonovsky 1996). Considering the roles of both the physical and social aspects of environments enables discussions on how place can enable and constrain behaviours which influence health. Socio-ecological models of research have been applied in many studies that explore how a multitude of health and wellbeing related outcomes are affected by elements of the physical and social environments in which we live. For example, this approach also allows us to consider psychosocial elements of health e.g. how residents' (and non-residents') perceptions of their neighbourhood might relate to health outcomes and mental well-being in particular (Macintyre et al. 1993). Furthermore, investigating the characteristics of places can provide insight as to why spatial and social inequalities in health might exist (Macintyre et al., 1993). More recently, the temporal nature of place has been recognised and there have been calls to integrate life course approaches into geographical investigations in order to enhance knowledge about the ways in which place is linked to health. Such approaches would enable, for example, assessment of the ways in which transitions between places throughout life and structural changes to the neighbourhoods in which people live, influence health and inequalities in later life (Pearce 2015).

Increasing attention from academics and policy makers across the world has focused on the potential 'salutogenic' effects of natural environments in particular e.g. parks, woodlands, beaches and gardens, and the ways in which they may be important for public health, particularly for those living in urban areas. Evidence suggests that living in areas with more green space is linked to lower stress (Roe et al. 2013), lower risk of diabetes and cardiovascular disease (Astell-Burt, Feng, et al. 2014; Mitchell & Popham 2008) and enhanced quality of life (Ward Thompson and Aspinall, 2011). Furthermore, it has also been shown in European countries, including the UK, that socioeconomic health inequalities are lower in neighbourhoods with greater amounts of green space (Mitchell et al., 2015; Mitchell & Popham, 2008). Specifically of interest has been the potential role of forests in supporting health. Unlike the studies above which explore links between all types of green space (collectively) and health, the research exploring the possible healing effects of forests in particular has largely been based in Japan where the practice of engaging with forests is called *shinrin-yoku* or 'forest bathing' (Tsunetsugu et al. 2010). The Japanese body of literature and studies in the UK/Europe have supported positive associations between either viewing or visiting forests and improved health-related outcomes including enhanced mood and reduced risk of poor mental health (Bielinis et al. 2018; Iwata et al. 2016; Komori et al. 2017; Mitchell 2013).

In this chapter, the theoretical perspectives and empirical evidence of the relationship between forests, health and inequalities are reviewed. The overall purpose of the research is to investigate changes in peoples' access to forests in Scotland over a 20-year period, explore relationships between forests and health through time and to assess potential implications for health inequalities. It is necessary to include relevant and up to date evidence in this review which then underpin the main aims of the study, provide contextual and policy background, and inform the methodological approach. Therefore, it is important that the review addresses the following key questions:

1. In what ways might forests be related to health? What are the key theories?
2. Which aspects and particular measures of health have been shown to be related to forests? Have disparities between social groups been identified?

3. In what ways can 'forest access' be conceptualised and measured?
4. Which theoretical perspectives might be helpful for explaining inequalities in forest access and possible implications for health inequalities?
5. Why might issues relating to changing forest access, health and inequalities be relevant for people living in Scotland in particular?
6. What have been the methodological approaches thus far for empirically investigating associations between forests and health? Could these approaches be enhanced?
7. Which longitudinal approaches might be useful for exploring associations between forests and health?

The above questions are used as criteria for selecting literature for review and critique. While the thesis focuses primarily on forests, insight is also drawn from the wider research on greenspace and other natural environments, where there is a lack of evidence specifically on forests.

2.1.1 Theoretical perspectives and pathways

2.1.1.1 Stress Reduction Theory and Attention Restoration Theory

There are two dominating frameworks which theorise the pathways through which forests may be related to health. Firstly, Stress Reduction Theory, also known as Psychoevolutionary Theory (Ulrich 1983), places emphasis on the natural environment's capacity to reduce feelings of stress. This theory focuses on the immediate positive emotional and physiological reactions to natural environments as the primary explanation as to why they are considered therapeutic (Hartig et al. 2003). Ulrich (1983) argues that contact with nature can quickly encourage feelings of positivity hence reducing feelings of stress and anxiety. The main underlying assumption of this evolutionary theory, that humans have a deep-rooted emotional connection with nature, is informed by biophilia and habitat theory.

The notion of biophilia was first proposed by (Wilson 1993) and is described as the ingrained tendency for fondness towards nature and natural environments and that this need is genetically based. Similarly, habitat theory is based on the basic assumption that humans are sensitive to and immediately reactive to their physical surroundings (Appleton 1975). The theory proposes that these perceptions are indicative of whether the conditions present in an environment are favourable for human survival (Danesh et al. 1999). Appleton (1975) proposes that environments which offer the opportunity for both ‘prospect’ (to have a reasonable view of surroundings), and ‘refuge’ (to have sufficient shelter from others), significantly satisfies the human need for survival and therefore may explain why humans may find forest environments particularly attractive.

Secondly, Attention Restoration Theory (Kaplan & Kaplan 1989) holds that contact with nature supports recovery from states of mental fatigue caused by the continuous demands and stress associated with everyday life in modern built environments. It is claimed that by providing psychological distance from mentally taxing environments, natural spaces help restore the brain’s capacity to concentrate, enabling recovery from fatigue (Tennessen & Cimprich 1995). Kaplan and Kaplan (1989) claim that there are four essential conditions for an environment or experience to be considered as attention-restoring. These include (1) effortless fascination, (2) sense of being away i.e. allowing escape from demanding routines, (3) sufficient extent with rich content which differentiates from everyday places and (4) compatibility with the individual’s aspirations (Hansmann et al. 2007). Although natural environments are not unique in offering these four qualities, Kaplan and Kaplan (1989) claim that they are particularly effective in doing so.

Whereas Ulrich’s (1983) theory places emphasis on the natural environment’s capacity to reduce feelings of stress, Kaplans’ (1989) focuses on recovering from mental exhaustion and restoring capabilities (Hartig et al. 2003). However, in practice, the two experiences are often linked. Ulrich et al. (1991) argues that the decline in performance experienced when one is mentally fatigued is due to the detrimental effects of stress. Kaplan (1995) highlights the challenge of studying stress and mental fatigue as they often occur together in research scenarios, which leads to the assumption that this is always the case in real life. Nonetheless, Kaplan (1995) attempts to clarify how stress and mental fatigue connect. Kaplan (1995) highlights the importance of harm (direct and threatening) and resource inadequacy (lack of psychological resources in order to handle difficult scenarios) in leading to how one responds to stress. However, as Parsons (1991) highlights, this perspective assumes that 'harm' is a prerequisite for stress and ignores that stress and fatigue can also be triggered by experiences in life which are mentally demanding yet rewarding e.g. starting a new job.

Although the above theories offer considerable analytical insight, their focus on early human experiences of natural environments is criticised. It has been suggested, due to rapid industrialisation, increasing urbanisation, advances in technology and accompanying cultural changes throughout the 20th century, that humans may have become emotionally as well as physically detached from the environments in which they evolved (Gullone 2000). It has also been suggested that biophilia is perhaps not always an important attribute in the relationship between natural environments and health and that cultural connections and individual characteristics and preferences are more likely to explain positive perceptions of and responses to nature (Grinde & Patil 2009). It has also been suggested that the positive connection between forests and health may be facilitated by mechanisms other than those relating to reduced stress and restoration, by improving air quality, social interaction and physical activity.

2.1.1.2 Enhanced air quality

Although evidence of an effect is weak, it is often proposed that forests contribute to human health directly by reducing pollutants such as ozone, nitrogen dioxide, sulphur dioxide and particulate matter. However, the extent to which forests mitigate air pollutants may only be slight. Research in the United States (US) demonstrated that the proportion of air quality improvements attributable to tree cover was less than one percent (Nowak et al. 2014; Nowak et al. 2006). On the other hand, it has also been suggested that forests have a role in producing particles that can harm health as trees release pollutants and allergens, including pollen, which can be detrimental to health particularly for those with asthma and hayfever (Lovasi et al. 2013). Again, evidence of this link is limited as studies in the UK and US did not find significant associations between risk of asthma hospitalizations and tree pollen counts (Osborne et al. 2017) or with percentage of evergreen forest cover (Erdman et al. 2015). A study carried out on green spaces in three European cities did not find air pollution to be a mediator in the relationship between green space and health (Zijlema et al. 2017). Alternatively, forests may influence health through indirect mechanisms e.g. by providing settings for social interaction and physical activity.

2.1.1.3 Social interaction and social cohesion

Studies have shown that forests promote social interaction and facilitate social cohesion which are proposed to be linked to mental health by providing protection against stress, sharing of health related information between peers and encouraging health-related behaviours (Kawachi & Berkman 2014; Cohen & Wills 1985). In the context of neighbourhoods, social cohesion often refers to the extent to which people feel that their residential area has a sense of community and belonging; the level of trust and friendliness between neighbours; and shared social norms and values (Forrest & Kearns 2001). A study in the US showed that levels of social interaction among neighbours and use of public spaces were higher in housing estates with vegetated spaces (trees and grass present) compared to those with concrete open spaces (Kuo et al. 1998). In the UK, studies have shown that forests provide opportunities for making social connections in the neighbourhood. Furthermore, study participants have reported enjoyment of socialising with others, meeting new people, becoming more involved in the governance and management of local community forests, and also the comfort felt when viewing other people enjoying the forest

(Carter et al. 2011; Dinnie et al. 2013; Edwards & Weldon 2006; Morris et al. 2011a; O'Brien et al. 2014). Social activities in forests have been found to be particularly beneficial for those suffering from depression, by offering opportunities for new social connections, working with others, feelings of increased confidence, contribution to society and creative expression (Townsend 2006). Such positive feelings are suggested to be linked to better mental health by moderating physiological responses to stress, aiding coping mechanisms and providing incentives for self-care e.g. exercising more, smoking less etc. (Cohen et al. 2000; Kawachi & Berkman 2014). Other studies have highlighted the importance of feeling safe and the quality of green spaces as potential moderating factors effecting the social pathways between green space and health (Kaźmierczak 2013; Maas et al. 2009).

Overall there is insufficient evidence to suggest that levels of social interaction mediate the relationship between forests and health outcomes. Studies thus far have reported mixed results and have examined green spaces collectively. Cross-sectional studies in European and Australian cities identified that social cohesion was a mediator in the relationship between perceived quantity and quality of neighbourhood green space and general and mental health (Sugiyama et al. 2008; de Vries et al. 2013; Zijlema et al., 2017) with social support being particularly important for men and those under the age of 65 (Dadvand et al. 2016). However, not all studies, including one from Europe, have detected these relationships (Triguero-Mas et al. 2015). This is possibly due to different types of green space appealing to different social groups and may also be due to the measure of social interaction or cohesion used. It has also been suggested that new methods of data collection, including GPS-tracking and those facilitated by smart phone applications which record the quantity of and type of interactions between people, may be important for providing a more detailed insight into social pathways (Markevych et al. 2017).

2.1.1.4 Physical activity

It is well known and accepted that achieving certain levels of physical activity is important for maintaining physical and mental health, by reducing the risk of depression and cardiovascular diseases, and by enhancing quality of life for people of all ages (Bize et al. 2007; World Health Organization 2018c). Forests may be linked to health by providing suitable settings for physical activity, mainly walking (Pietilä et al. 2015; Ward Thompson & Aspinall 2011) but also cycling and children's play (O'Brien 2006). Studies in Scotland, South Korea and Switzerland have also suggested that physical activity in forests supports mental health more so than physical activity indoors. Participants who exercised in forests reported more pronounced feelings of stress relief, happiness and being more mentally balanced than those who exercised indoors. Participants also had a lower risk of poor mental health compared to those who exercised indoors or in other types of green spaces and blue spaces (Hug et al. 2008; Mitchell 2013; Shin et al. 2013).

Evidence supporting whether physical activity mediates the relationship between forests and health is weak. There have only been a few green space studies in England and Europe which found that physical activity was either a partial mediator with low explanatory power (Dadvand et al., 2016) or did not mediate associations between green space and health (Lachowycz & Jones 2014; Zijlema et al., 2017). Furthermore, green space studies have also found a negative association between the amount of green space and people's physical activity levels. This may be due to areas with more green space also being further away from everyday destinations like grocery stores, schools, places of work etc. and therefore being located in areas where people are less likely to walk or cycle (Hartig et al. 2014; Markevych et al. 2017).

2.1.2 Testing pathways between forests and health

As demonstrated above, several potential pathways might explain the connection between forests (or green spaces) and health, which are shown in Fig. 2.1. However, evidence has been weak and there are few studies which have explicitly tested mediation using statistical techniques. Furthermore, results have been inconclusive, and mediators have varied according to social groups and particular indicators of health. Therefore, although forests may provide people opportunities to improve aspects of their health, there is little convincing evidence of clear pathways between these environments and specific health outcomes. Little attention has been paid to how opportunities to engage with forests to improve health may be shaped by a number of structural factors which determine where forests are located, such as the level of public access. As illustrated in Fig.2.1, people's level of forest access may be influenced by their opportunities to participate in decision-making relating to choice of residential location and environmental planning. Furthermore, opportunities to visit forests are also shaped by individual preferences about forests and their neighbourhood, which in turn may be influenced by an individual's characteristics, past experiences, and emotional and cultural connections to forests. The ways in which these factors operate over time has largely been ignored in previous literature but they are important determinants of the timing and accumulation of people's exposure to forests throughout their lives.

This chapter turns now to the current empirical evidence linking forests, health and inequalities.

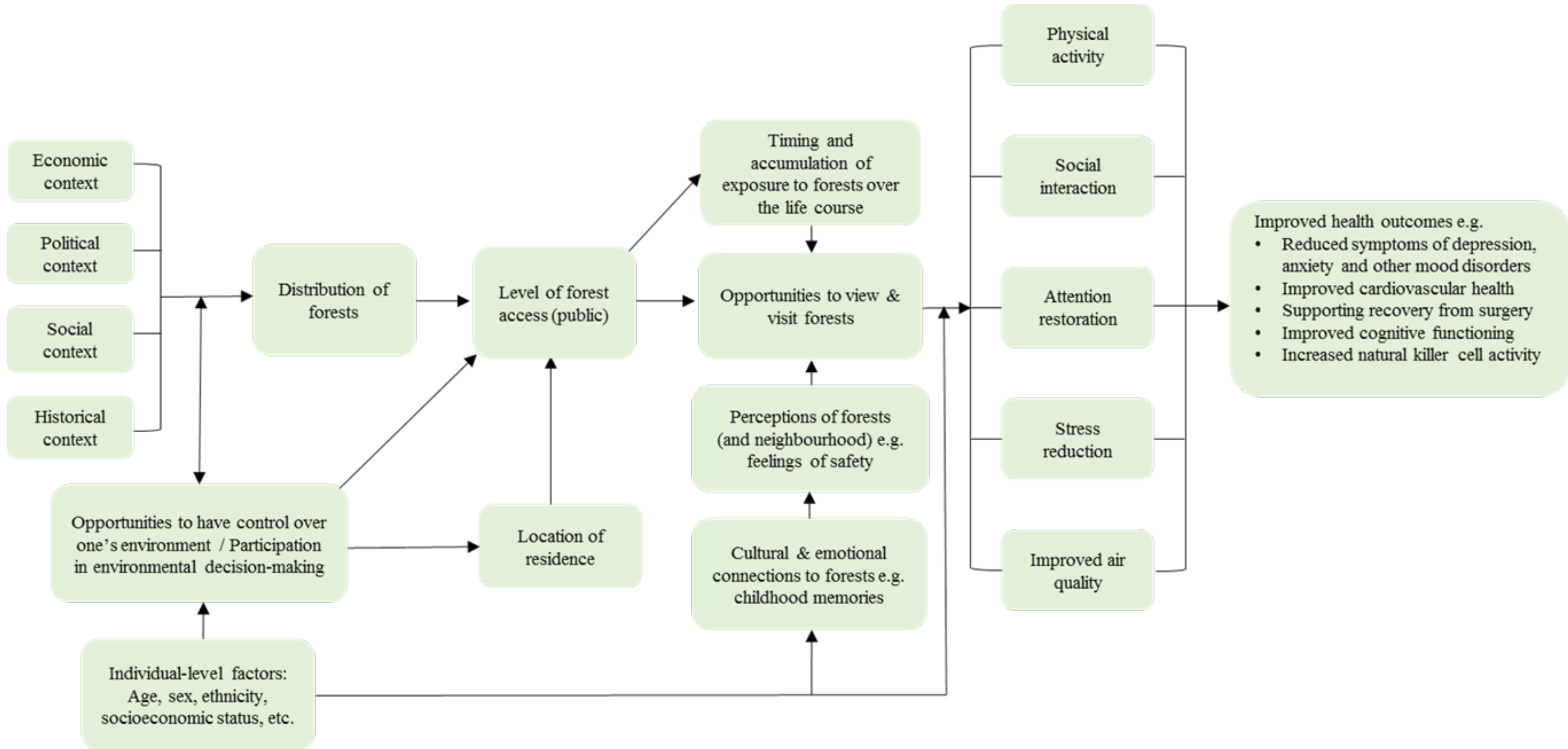


Fig.2.1: Conceptual framework of the relationship between forest access and health, integrating principles of environmental justice and socio-ecological models of health inequalities. Adapted from Hartig et al., (2014).

2.2 **Forests, health and inequalities: the empirical evidence**

Studies from across the world have suggested that engaging with forests may help improve physical and mental health outcomes. Positive influences have been demonstrated for people maintaining good health who visit local forests recreationally and those with illness who participate in forest therapy programmes.

Much of the evidence supporting possible therapeutic effects of forests has come from Asian countries including Japan, China and South Korea, with a smaller number from Europe. Most studies have focused on stress but there is also some evidence of links between forests and physical aspects of health. These include but are not limited to conditions such as hypertension (Morita et al. 2011; Song et al. 2017; Sung et al. 2012); lung disease (Jia et al. 2016); enhancing immunity against cancer (Li & Kawada 2011; Li et al. 2010; Li et al. 2008; Tsao et al. 2018); improving cardiovascular health (Mao et al. 2018; Mao et al. 2012; Sung et al. 2012b); and supporting recovery from surgery (Ulrich 1984).

A range of physiological and self-reported markers have been used to measure associations between forests and feelings of stress. Studies have shown that, in comparison to viewing urban landscapes, participants experienced lower blood pressure and lower heart rate variability when viewing forests (Lee et al. 2009; Park et al. 2010a; Takayama et al. 2014). Experiments have also shown reduced blood pressure, pulse rate and salivary cortisol (stress hormone) concentration when walking in the forest compared to walking in an urban environment (Kobayashi et al. 2017; Komori et al. 2017; Lee et al. 2014; Lee et al. 2011; Li et al. 2011; Park et al. 2010; Park et al. 2009; Park et al. 2008; Toda et al. 2013; Tsunetsugu et al. 2007). One study in Korea found increased parasympathetic nerve activity (indicator of calmness) among those who participated in a 6-week forest-walking program, compared to a control group who maintained their normal physical activity levels during the study period (Bang et al. 2017). Particular aspects of brain health have also been used as measures of stress. A cross-sectional study in Berlin showed that older adults with more forest cover around their home had healthier amygdala structure, indicating higher ability to cope with stress (Kühn et al. 2017). Similar findings were also found among Japanese males whose parasympathetic nerve activity significantly increased and sympathetic nerve activity (response to threat) significantly decreased in forests but not when in urban environments (Lee et al. 2011).

Subjective measures such as the Profile of Mood Score (POMS), Beck Depression Inventory, Hamilton Rating Scales for Depression (HRSD) and the Montgomery-Asberg Depression Rating Scales (MADRS) support a positive influence of visiting forests on stress and various other aspects of mental health (Bang et al. 2017; Mao et al. 2012; Toda et al. 2013; Sung et al. 2012). Studies have found reduced feelings of stress, anxiety, anger-hostility and exhaustion (Hansmann et al. 2007; Morita et al. 2007; Park et al. 2011; Tsunetsugu et al. 2011) and increased feelings of positivity, relaxation, restoration and enthusiasm (Bielinis et al. 2018; Kondo et al. 2008; Stigsdotter et al. 2017; Shin et al. 2013; Takayama et al. 2014) after visiting forests. However, significant differences in mood between treatment and control groups are not always identified (Komori et al. 2017). A number of Asian and European studies have also linked forests to reduced symptoms of mental illness including depression, anxiety and bipolar disorder (Iwata et al. 2016; Kim et al. 2009; Nordh et al. 2009; Shin et al. 2012; Sonntag-Öström et al. 2011;).

As demonstrated, there are many health outcomes that have been associated with forests. However, studies also suggest that the potential health benefits of forests might be unevenly shared across the population and that some groups are more likely to benefit than others.

2.2.1 Differences across sociodemographic groups

2.2.1.1 Age

Some evidence suggests that the influence of forests on health varies by age. This has been demonstrated by several experiments carried out in Japan and Republic of Korea. Studies have shown reductions in physiological (blood pressure, salivary cortisol and heart rate) measures of stress, improvements in self-reported mood, depression and quality of life for middle aged and older people who visited forests, compared to a control group who were not exposed to forests (Horiuchi et al. 2013; Matsunaga et al. 2011; Sawa et al. 2011; Shin et al. 2012). Reductions in anxiety, confusion, anger hostility and increased feelings of hope and enjoyment were also reported by those in the same age groups (Horiuchi et al. 2013; Matsunaga et al. 2011; Shin et al. 2012). Furthermore, it has been suggested that the ways in which forests facilitate physical activity and socialising and reduce feelings of loneliness have shown to be particularly important for older and retired people (Morris & O'Brien 2011; O'Brien et al. 2010; O'Brien & Snowdon 2007; Tabbush 2010).

2.2.1.2 Sex

Differences in relationships between green spaces (not specifically forests) and health by sex have been identified for a range of outcomes, including mental health, with green spaces favouring women (van den Bosch et al. 2015); and cardiovascular and general health with green spaces favouring men (Richardson & Mitchell 2010). Qualitative research specifically on forests has also demonstrated that organised activities, e.g. ranger-led walking groups, are particularly important for women in encouraging socialising and physical activity in forests (Morris et al. 2011a; Morris & O'Brien 2011). This may reflect what has also been suggested about women's access to forests, i.e. that women may have a tendency not to visit forests alone, due to concerns about personal safety. These concerns are thought to arise from negative personal experiences; the way in which forests are portrayed in the media; and societal beliefs about what is considered safe behaviour, which act as strong barriers for women (Krenichyn 2006; Morris et al. 2011b).

2.2.1.3 Deprivation, inequalities and 'equigenesis'

Previous studies in the UK suggest that forests and other types of green space in urban deprived areas enhance quality of life, reduce feelings of stress and provide relaxing places away from busy built environments, for those living there (Roe et al. 2013; Ward Thompson et al. 2012; Ward Thompson & Aspinall 2011). A study in Florida found a positive influence of neighbourhood greenness on reducing chronic diseases such as hypertension and diabetes, and that these relationships were stronger for those living in less affluent areas (Brown et al. 2016). It has also been proposed that the opportunities for social interaction which forests provide are particularly important for those living in low-income households or deprived areas (O'Brien 2005; O'Brien & Morris 2009b; O'Brien & Morris 2009a). It is possible that green spaces in deprived areas may modify the link between poverty and poor health through a combination of psycho-social and physical pathways and that green spaces could be labelled as 'equigenic environments' i.e. those that can weaken the relationship between socioeconomic inequality and health inequality (Mitchell et al. 2015; Mitchell 2013; Mitchell & Popham 2008). Studies which have investigated the distribution of green spaces and their contribution to health inequalities include the work by Mitchell & Popham (2008). This study, based in England, found that inequalities in mortality were smaller between income-deprived and affluent areas with more green space, than in those with less green space. Similar effects were found in a study of urban residents across 34 European countries. This study showed that the gap in mental wellbeing score between individuals who reported high and low levels of financial strain was narrower for those with better access to green and recreational areas (Mitchell et al. 2015). However, no studies have examined changes over time in people's access to forests in particular and the possible implications for subsequent health outcomes and later socioeconomic health inequalities. Such evidence would advance knowledge on how engaging with forests may help improve people's long-term health and inform strategies on the role of forests in reducing health inequalities.

In summary, studies have shown that not all population groups may gain the prospective health benefits associated with forests, suggesting that barriers which prevent or discourage certain groups from accessing or visiting forests may exist. Therefore, uneven patterns of forest access and use may contribute to health inequalities. However, across health studies, there has also been little reflection on how access to potentially therapeutic environments has been conceptualised and measured.

2.3 **Forest access and use**

2.3.1 Conceptualising forest access

In Scotland, the public have access rights to all forests for recreational purposes, by law under the Land Reform Act 2003 (Fairburn et al. 2005). However, empirical studies in Scotland and elsewhere (e.g. England, Norway and Australia) suggest that a range of physical and environmental factors have a major role in determining whether forests are perceived to be publicly accessible and likely to be used for recreation. Close access to home and being easy to reach by foot, bike or car is commonly found as a factor determining frequent use of forests (Coles & Bussey 2000; Dallimer et al. 2014; Koppen et al. 2014; O'Brien 2005; Ward Thompson et al. 2004). Studies also highlight the importance of the forest's physical context including the presence of visible access points, footpaths (Carter & Horwitz 2014) and way marking signage (Doick et al. 2013). Diverse forests, in terms of tree species and age, are also considered more attractive to visitors (O'Brien & Morris 2014). This finding is also reflected in the work surrounding the therapeutic effect of green spaces collectively, which suggests that the psychological benefits of green spaces increases with species richness (Dallimer et al. 2012; Shanahan et al. 2015).

The evidence also suggests that perceptions of forests and what makes a forest accessible, varies by social group. Older people, those with mobility impairments and those less familiar with visiting forests prefer forests which are managed with good quality foot paths, information boards, maps, benches, toilets and car parks (Koppen et al. 2014; O'Brien et al. 2014; Ward Thompson et al. 2004). Overall, the evidence identifies several different features which determine whether forests are perceived as practically accessible to the public.

Although these factors vary between social groups and individual needs, it appears that forests which are in close reach of populations and easy to reach by road or footpath, and those which contain a network of access routes i.e. roads, paths and tracks, are more likely to be positively perceived and used recreationally.

2.3.2 Measuring forest access in health research

There has been little research into the links between people's level of forest access and health outcomes; however, insights into how access is measured may be drawn from the wider green space and health research. The methods adopted in order to measure access vary between studies and there is not an accepted definition of 'good access' to green spaces. Thresholds or specified distances at which people should live from green spaces in order to gain the associated health benefits are also inconsistent.

People's level of access has usually been captured through the use of GIS-based techniques which have measured either the Euclidean (crow-fly distance) or network distance from an individual's place of residence to the nearest green space. A study examining distance between public parks and place of residence in different socioeconomic areas of Glasgow measured Euclidean distance between participants' homes and the boundary of the nearest park (Macintyre et al. 2008). Potential levels of access have also been measured by conducting buffer analyses. For example, in a study on access to urban green ways for different socioeconomic groups in the city of Indianapolis (US), Lindsey et al. (2001) created a buffer of 0.5 miles around the boundary of green way trails and examined the proportions of socioeconomic groups within this buffer.

Alternatively, studies that have been able to access spatial data on transport networks have calculated the route distance between green space and participants' homes via roads and footpaths. A study based in Norwich measured distance by road from residential location to nearest green space entrance point (Hillsdon et al. 2006). However, due to lack of data availability, calculation of network distances is not often possible. The full residential address of study participants is not usually contained in social and health data sets or has not been geocoded. Therefore, in most studies, estimates of green space access are calculated using the centroid of the participants' postcode area (or larger administrative geography) as the starting point. Furthermore, distance to the nearest green space boundary is often calculated, rather than the distance to the nearest green space access point, as this level of detail is also not usually available in regional or nationwide data sets.

It has been recommended that, where possible, both Euclidian and network distances should be included in analyses as they can provide different results (Hillsdon et al. 2006). It has also been argued that, although crow-fly distance is often the easiest solution to measuring distance, network approaches can offer a more realistic representation of access. This is because analysis of transport routes may also give an indication of how practically easy places are to access, particularly by foot (Gascon et al. 2015).

As demonstrated, different methods of measuring access to green spaces have been adopted and often depend on data availability. However, as a guide, national benchmarks are often referred to in policy documentation. The Accessible Natural Greenspace Standard (ANGST), designed by Natural England, states:

- No person should live more than 300m from their nearest area of natural green space of at least 2ha in size.
- There should be at least one accessible 20ha site within 2km of home.
- There should be one accessible 100ha site within 5km of home.
- There should be one accessible 500ha site within 10km of home.

(Mckernan & Grose 2007).

Another example specifically relating to forests is the Woodland Access Standard. This was developed by the Woodland Trust as part of their project - Spaces for People: Targeting Action for Woodland Access. The Standard states:

- No person should live more than 500m from at least one area of accessible woodland of no less than 2ha in size.

- There should be at least one area of accessible woodland of no less than 20ha within 4km (8km round trip) of people's homes

(Woodland Trust 2015).

In the UK and other European countries, some studies have used these Standards to define 'good access' in their investigations of the relationships between green spaces and health where 300m or 500m has been considered walking distance (Kessel et al. 2009; Kuta & Ajayi 2014; Markevych et al. 2014). However, other thresholds which might be important for health outcomes have also been identified. People living within 300m of green spaces have shown to have fewer symptoms of depression and better self-reported general health than those living further away (Reklaitiene et al. 2014). Similar findings have also been found using a threshold of 400m (Sturm & Cohen 2014). However, a study in Los Angeles showed that green spaces further than 300m may also be important and that people living between 300m and 1km of a green space had comparable health to those living within 300m (Stigsdotter et al. 2010).

As demonstrated in the above examples, there is little consistency or agreement on which levels of forest and green space access are important for health. Previous studies also suggest that important thresholds may vary between different aspects of health, countries and social groups. Therefore, future studies in the field should conduct sensitivity analyses, testing different thresholds other than the current benchmarks to ascertain which of these are most important for the health outcomes being investigated. One remaining limitation of using measures of people's access to forests is that it does not indicate much about people's use of forests. This information is not available in nationwide longitudinal surveys also containing detailed measures of health. Therefore, it is difficult to assess relationships between people's actual engagement with forests and specific health outcomes for populations.

2.3.3 Predictors of forest use and associations with health

Previous studies suggest that some socio-demographic groups are more likely to use forests than others. Forest use has been found to vary by age, gender, socioeconomic status (measured by housing tenure, education, income and social grade) and ethnicity (Morris et al. 2011a; Ward Thompson et al. 2005). Other factors for adults include childhood visits to forests, dog ownership and having cultural or emotional associations with forests (Ward Thompson et al. 2004). Also, drawing on some examples from the green space literature, marital status and having children in the household have been found to be important for visiting green areas in the UK and Denmark (Irvine et al. 2013; Schipperijn et al. 2010;). Preferences about forests and green spaces have also been found to vary among social groups. It has been identified that families with young children require safe routes to the green space and prefer the provision of play and sports facilities, cycle friendly paths and designated areas for dogs (Barbosa et al. 2007; Morris & O'Brien 2011; Sanesi & Chiarello 2006).

Geographical and social environmental factors which are important for determining people's use of forests and other types of green space have also been investigated. Studies have highlighted the importance of close proximity in encouraging frequent use and interventions that enhance the physical aspects of forests e.g. new footpaths. It is also suggested that a degree of social engagement is necessary for interventions to be successful (Dallimer et al. 2014; Seaman et al. 2010), particularly those that consider neighbourhood characteristics including deprivation, cultural history, social cohesion, feelings of safety and people's perceptions, experiences and memories of the area (Jorgensen & Anthopoulou 2007; Lo & Jim 2010; Sanesi & Chiarello 2006; Seaman et al. 2010).

Fewer studies have been able to ascertain how forest use relates to health or whether there are specific usage thresholds that are important for gaining any associated health benefits. Those identified include two studies in the UK which found that people who visited forests at least weekly were significantly less likely to have poor mental health than people who did not visit (Cox et al. 2017; Mitchell 2013). However, another study in Scotland highlighted similarities in characteristics and perceptions of forests between those who visited monthly and weekly; and between those who never visited forests and those who only visited annually (Ward Thompson et al. 2004).

As demonstrated in previous research, a multitude of demographic, social and environmental factors which may potentially determine levels of forest access and likelihood of use have been identified. Also, the levels of forest access and use which may be important for health are likely to vary between places, social groups and the specific aspect of health studied. Furthermore, it has not been considered how differences in forest access (and inequalities in the potential health benefits of forests) are produced and whether these develop over time through changes in structural factors. Focusing on Scotland, the next section explores the key structural shifts which may have influenced levels of forest access among the population.

2.4 A brief history of people's forest access in Scotland

This section discusses the key developments in forest policy, practices, cultural views and technology which have shaped the geography of forests in Scotland, and the impact of these structural changes on people's forest access. The key transitions in forestry from the end of World War Two (WW2) to the decades leading up to and included in the study period are discussed. In particular, research in this field has focused on the ways in which changes in policy, practice and wider structural and economic factors have influenced public perceptions of forests and have affected social patterns of forest access. These factors are summarised in a timeline in Fig.2.2. Mather (2001) describes the main change in forestry as a shift from 'forests of production' (emphasis on timber production) to 'forests of consumption' (emphasis on recreation and biodiversity).

2.4.1 Forests of production (1945-1980)

Throughout the 1900s, the amount of forest area in Scotland grew dramatically after much was lost in order to meet demands for agricultural land and timber in previous centuries (Mather 2004). Due to rapid depletion of the UK's timber resources, the precarious nature of imports during World War Two and the increasing demand for timber in the growing mining industry, an especially intense period of forest planting was triggered. It is estimated that the amount of forest cover expanded by over 20,000ha per year between 1950 and 1990. This growth mainly consisted of large-scale plantations containing conifer species which were low-maintenance and could withstand poor soil, steep inclines and harsh weather conditions (Thomas et al. 2015). To encourage rapid expansion of forests, the UK Government offered generous tax incentives and subsidies for land owners and farmers. This included the Forestry Commission Dedication Scheme and Afforestation Program which focused on post-war expansion of food production as well as forestry. These two land uses were geographically determined, whereby fertile soils of the Scottish Lowlands were exclusively reserved for agriculture and the vast areas of land unsuitable for crop production but habitable for conifer species in the upland areas of the country were used for forest plantations. The process was largely unregulated and local communities and organisations were not consulted on plans for commercial planting. Decision-making in the industrial forestry period was confined to private land owners, farmers, high earners and high tax payers who were exclusively favoured by the Government's unregulated financial support and geographical sorting of commercial forestry developments (Foot, 2003). Forests were 'out of sight, out of mind' for the general population, 80% of which resided in Central or Lowland Scotland at the time of the 1951 census (Kyd 1952). Throughout the 1950s and 1960s, planting 'forests of production' continued to be supported by new legislation, tax structures, commercial developments in the private sector and advancing machinery including the invention of the chain saw. The 1951 Forestry Act was introduced which required all felled areas to be replanted. Land owners and private firms could also divert tax liabilities to woodland creation opportunities which sparked the formation of the Economic Forestry Group of companies, currently known as Tilhill, Fountain Forestry and Scottish Woodlands (Foot 2003). However, also during the 1960s, increasing affordability of cars meant that people were more mobile than before and more inclined to visit the countryside for recreation. Mather (2001) describes these changes as the start of post-productivist and post-materialist trends by which increasing urbanisation, wealth and improved technology triggered changes in the ways people related to natural environments and forests in particular. Visits to rural areas increased in popularity as people became more connected with the outdoors but complaints were made by the public and wildlife organisations such as the Royal Society for the Protection of Birds. Visitors and conservationists were disappointed with the forest experience and described the landscape as 'artificial', dominated by blocks of foreign conifer species which contained little wildlife (Foot 2003). Throughout the 1970s and 1980s, connections between people and biodiverse forests strengthened through increasing campaigns for 'multipurpose' forestry whereby the industry would serve ecological, social and recreational purposes as well as economic (Forestry Commission 2017a; Woodland Trust 2017).

2.4.2 Forests of consumption (1980s onwards)

In the early 1980s', the long-running Dedication Scheme was terminated and replaced with short-term grants by the Conservative Government. Additionally, introduction of the Wildlife & Countryside Act (1981) and Sites of Special Scientific Interest (SSSIs) presented new challenges for commercial foresters and landowners to continue planting for the sole purpose of producing timber. Requirements for public access, biodiversity enhancement and aesthetics were now in place in order to obtain funding to plant and maintain forests. Furthermore, the introduction of the Farm Woodlands Premium Scheme and the possibility of overlapping various farming activities with forestry, along with the increasing public interest in the recreational and ecological value of forests, gradually brought forests closer to the more populated areas of the Scottish Lowlands throughout the 1980s, 1990s and 2000s (Foot, 2003).

The broadening of funding sources from national charities, including the National Lottery Fund and development of new local charities such as Central Scotland Forest Trust, meant that small forests for access and recreation could be planted and maintained in areas much closer to urban populations (Foot 2003), and particularly in areas characterised by heavy industries which were now declining. The introduction of the Scottish Forestry Strategy in 2000 by the Scottish Executive reflected the changes in relationship between people and forests throughout the 20th century and the need for publicly accessible forests which provided environmental and social benefits to the population. New funding programmes and changes in European agricultural policy made forestry a viable activity for lowland farmers as they now could receive annual payments for planting and maintaining areas of woodland on their land. Such opportunities for forestry were previously only available to the remote, rural areas of upland Scotland (Mather 2004).

More widely, issues of climate change and sustainable development were becoming high on political agendas, including the role of forestry as carbon sink. Key meetings in the 1990s highlighted the importance of diversifying the forestry industry and marked the international acceptance of the social and environmental benefits of ‘multipurpose forestry’. These included the UN conference on Environment & Development (Rio de Janerio, 1992) and the Ministerial Conference on the Protection of Forests in Europe (Helsinki 1993 & Lisbon 1998).

Whereas forestry was previously an industry created purely to resolve the post-war timber shortage, it had now diversified into one which delivers many public benefits. These benefits included: supporting rural economies through farm diversification; improving quality of life by providing educational and recreational opportunities to communities and enhancing biodiversity especially in urban areas; and helping to offset the impacts of climate change through sustainable flood management schemes and by absorbing greenhouse gas emissions (Forestry Commission Scotland 2009a; Scottish Executive 2006). In particular, the potential health benefits of forests were beginning to be recognised. Increasing forest access in populated areas, especially those that are deprived, became a priority of Forestry Commission Scotland and funding was made available through new schemes such as Woods In And Around Towns (WIAT), launched in 2005, in order to plant, manage and enhance urban forests, particularly in deprived areas (Forestry Commission Scotland 2016). A recent evaluation of WIAT estimated that the amount of visits to WIAT funded woods by those with low socioeconomic status rose by 17% from the beginning of the scheme in 2005 to 2011 and that the most benefits were found in communities where local people already had a connection to woods such as through an active Friends group (Ambrose-oji et al. 2014). Community engagement and partnering with Local Authorities in delivering recreational and health benefits of woods to local people was emphasised as a key element to successful WIAT projects (Ambrose-oji et al. 2014). Evaluation of the WIAT scheme continues with a longitudinal study currently being undertaken to investigate the possible mental health benefits of WIAT interventions at the neighbourhood scale (Silveirinha de Oliveira et al. 2013).

2.4.3 Current knowledge on levels of forest cover and public access

In 2017 it was estimated that there were 1.44 million hectares of woodland in Scotland, which is 18% of the country's total land area. This included all areas of trees which are at least 0.5 hectares in size. Approximately two thirds of Scotland's forests are owned by local authorities, private companies, other organisations and individuals (Forestry Commission GB 2017). The remaining third is known as the National Forest Estate (NFE) which is owned and managed by Forestry Commission Scotland.

In 2017, a study by the Woodland Trust estimated that there were 765,204 ha of forests which were accessible by the public, a 2% decrease from 2015, and that 32.4% of the

Scottish population lived within 500m of those forests (an approximation of 'within walking distance'). This proportion varied by local authority. More populated areas including West Lothian, East Dunbartonshire and Dundee City had the highest proportions whilst the Orkney Islands, Shetland Islands and South Ayrshire which are less populated and coastal, had the lowest levels of forest access (Woodland Trust 2017). In terms of people actually visiting forests, findings of a nationally representative survey showed that 20% of the Scottish population visited forests at least monthly during 2013-2014 (TNS 2014b). Forestry Commission Scotland also estimated that there were 9.1 million visits to the National Forest Estate from November 2012 to October 2013. This is approximately 5% more than that recorded in the previous survey which took place from June 2004 to June 2007 (TNS 2014a).

Whereas previous research suggests that forest access has improved in Scotland, empirical studies have not considered whether changes in forest access have been uneven across different areas of Scotland e.g. between deprived and affluent areas. Furthermore, no studies to date have explored this question as a potential environmental justice concern and whether uneven distributions of forests may be related to health inequalities.

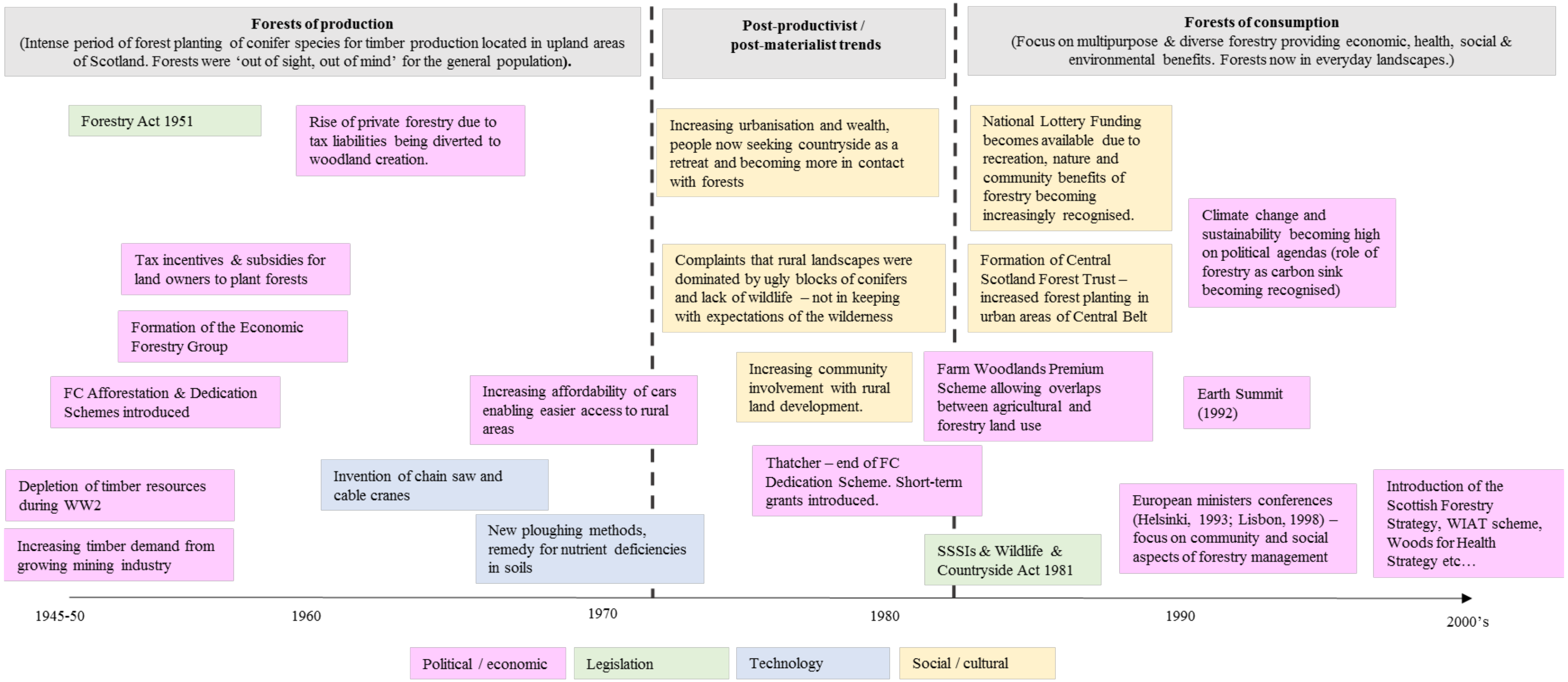


Fig.2.2: Key structural factors in the shift from 'forests of production' to 'forests of consumption' in Scotland. Based on Foot (2003), Mather (2004), Mather (2001).

2.5 Environmental justice

Studies of environmental justice first emerged in the United States (US) during the late 1970s and early 1980s. Investigations focused on the uneven distribution of hazardous waste facilities and demonstrated that these were predominantly situated in areas within close proximity of ethnic minority communities (Brulle & Pellow 2006). Furthermore, race was found to be the most powerful determinant of where hazardous waste sites would be located (United Church of Christ 1987). Since then, environmental justice concerns have broadened beyond discussions about race and civil rights in the US to consider the ways in which other potentially vulnerable populations elsewhere may be disproportionately burdened by a range of health-damaging environmental issues, including the impacts of climate change (Wilson et al. 2010) and gentrification (Anguelovski 2015). In the UK, studies suggest that those living in deprived areas (Richardson et al. 2010; Shortt et al. 2014) and those with lower income (Fairburn et al. 2005) are groups more likely to live in close proximity to pathogenic environments. People living in areas of multiple environmental deprivation are also more likely to have poor health than those in areas containing less pathogenic features (Pearce et al. 2010).

Research into environmental justice has also explored the ways in which health-promoting environments might be unevenly distributed across the population. Findings have illustrated that disadvantaged or minority groups have poorer access to environmental ‘goods’, such as green spaces and blue spaces, in comparison to more advantaged and wealthier groups. There are very few studies which focus on environmental justice issues with regards to forest access in particular; however, research largely focused on, but not limited to, North America suggests that access to green spaces, increased tree canopy cover and street greenery, was greater for residents of more affluent communities (Lakes et al. 2013; Li et al. 2015; Schwarz et al. 2015; Sister et al. 2009; Wolch et al. 2014). However, other research reports mixed findings. In the city of Sheffield in the UK, people in more disadvantaged groups had the greatest access to green space (Barbosa et al. 2007). Also, in a southern US county (anonymised by authors), the distribution of parks was found to not be significantly related to neighbourhood deprivation (Hughey et al. 2016).

It has been suggested that poorer access to health promoting environments may offer a partial explanation for why those in lower socioeconomic groups or those living in deprived areas also tend to have worse health outcomes than those in more advantaged groups (Shortt et al. 2014). However, this has rarely been investigated in studies focused on environmental justice and has not yet been examined specifically in relation to forest access. Within the environmental justice framework, there are four key concepts which help to explore possible explanations for uneven access to forests and the possible uneven distribution of the associated health benefits. These are (1) distribution, (2) recognition, (3) participation or procedural issues, and (4) capabilities (Schlosberg 2007). They are linked concepts, which help us to consider the different factors and processes that contribute to environmental justice problems. Fig.2.3 summarises these concepts and shows how they can be related to forests and health inequalities.

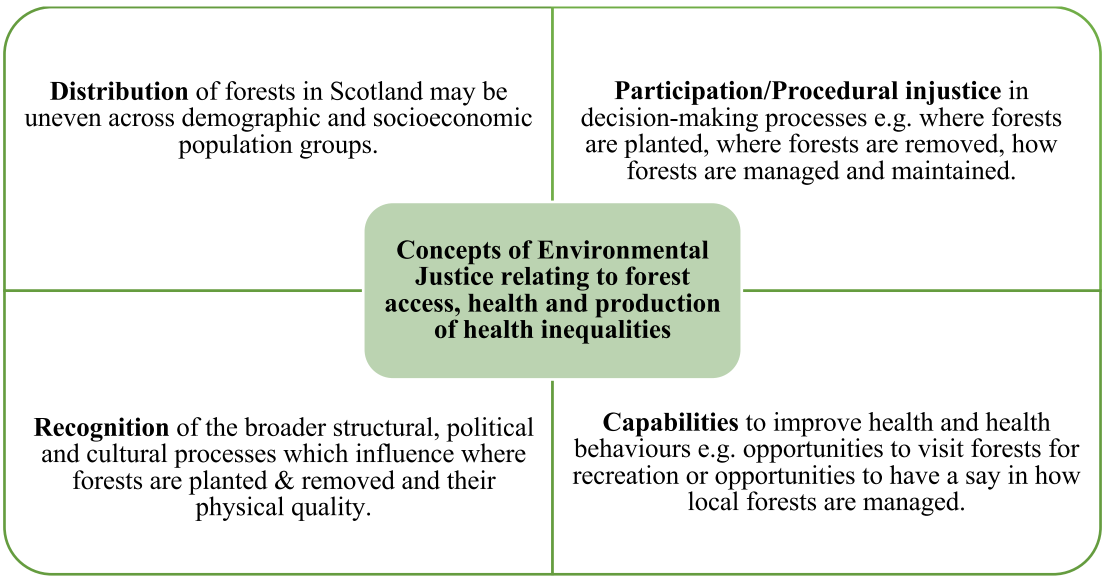


Fig.2.3: Concepts of Environmental Justice relating to forest access, health and production of health inequalities.

Firstly, much of the literature on justice has focused on the unequal *distribution* of environmental resources, goods and services and it has been argued that the concept of justice is only applicable where there is a distributive issue (Dobson 1999). However, the distribution approach is commonly criticised for failing to recognise the underlying social contexts and broader structural processes that create the uneven distribution in the first place (Young 1990). Furthermore, discussions about injustice should not just involve describing the uneven distributions of environment but also reflect *recognition* of the key structural, political and economic processes which produce them. In terms of the distribution of forests in relation to populations, macro-level factors may include government policies, public funding arrangements and land availability which direct forest planting opportunities to certain parts of the country and not others (as discussed in section 2.4). Another structural factor might be the affordability and availability of housing, which may exclude poorer people from living near forests. In Scotland, the price of land in close proximity to green spaces can have up to a 20% premium compared to areas without good access (Scottish Natural Heritage 2014).

Linked to the notion of recognition is *participation* or *procedural* environmental justice, which refers to the transparency and inclusivity of environmental decision-making processes (Aragão et al. 2016). In order for justice to be achieved, political processes must be participatory and democratic across the population (Young 1990). This approach considers the factors which restrict the ability of individuals and groups to participate in the wider community and political decision-making. Some social groups may be more likely than others to participate in public consultations about plans to plant, fell or maintain forests in their local area (Bell 2011). Therefore, it is possible that some viewpoints are not included in the discussion and considered in the decision-making process, which leads to forest access only being improved for those groups who are able to participate.

Further to this, the capabilities approach considers the inequity of opportunities across the population and emphasises that it is the extent of opportunities that people have for achieving what they consider good things in life, which is important for their health and well-being (Anand et al. 2005). It places emphasis on what people are capable of doing rather than the resources they have or their actions. It acknowledges that an individual's opportunities and capabilities to improve their health are shaped by the social contexts in which they live and wider structural and political factors. The capabilities approach is useful for understanding the link between health inequalities and forest access in several ways. It is a broad and flexible framework considering the many different factors and levels intertwined in people's life, which may contribute to health and well-being. It takes into consideration aspects to do with lifestyle and maintaining physical and mental health at the individual-level and the important influence of being connected to and participating in wider political and structural processes. This includes the ability to have an opportunity for play and recreation. As suggested in section 2.2.1.2, women may be less likely to visit forests for recreation due to societal beliefs about responsible behaviour and concerns for personal safety which are amplified in the media. Also emphasised is the opportunity to have *"control over one's environment"* (Nussbaum 2003 pg.42) which directly links to procedural environmental justice and having the opportunity to participate in discussions and decision-making which affects people's access to forests.

Concepts of environmental justice consider the ways in which structural factors may have produced (and possibly maintained) uneven distributions of forests and inequalities in people's forest access. Conducting this study within a framework of environmental justice allows investigation into the broader structural mechanisms through which uneven patterns of forest access and inequalities in health are produced (Shortt et al. 2014). However, studies focusing on environmental justice have tended not to take a longitudinal approach and consider how environmental injustices have been produced over time. Thus far, studies on forests and health inequalities have been limited due to cross-sectional designs, which do not allow understanding of how changes in forest access may be related to changes in health; and the widening or narrowing of health inequalities over time. Previous research suggests that temporal approaches could provide important insights as environmental risk factors may accumulate over the life course and influence health in later life (Curtis 2004). Also, there may be critical periods in a person's life where exposure to particular environments is linked to health outcomes in older age (Pearce et al. 2016). Other possibilities include investigation into potential links between the histories of individuals and the places where they previously lived and their current health (Hladnik & Pirnat 2011). None of these questions have yet been explored in relation to people's forest access. The consideration of life course approaches and information about places, people and their health at different time points would provide a more thorough understanding of how forests influence health over time and is likely to provide important evidence for informing policy and interventions targeted at reducing health inequalities (Niedzwiedz et al. 2012). The next section further explores life course approaches and longitudinal study designs and discusses how they are useful for advancing knowledge on forests, population health and inequalities.

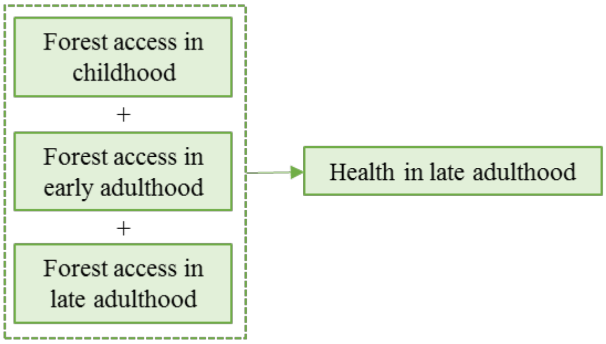
2.6 **Life course approaches and longitudinal study designs**

2.6.1 Life course models of health

Life course epidemiology has made significant contributions to the ways in which we understand population health. Interest in life course approaches has arisen from increasing awareness that exposures and experiences in early life influence mental and physical development and that this contributes to many health outcomes in adulthood (Wadsworth et al. 2007). Across the literature on environments and health there has been little attention paid to how people's access to salutogenic environments such as forests change over time and there have been no studies to date which use life course models of health to investigate potential ways in which different levels of forest access throughout life might be linked to health in later life. There are three main life course models of health suggested in the literature (Ben-shlomo & Kuh 2002; Ben-Shlomo & Kuh 1997; Niedzwiedz et al. 2012). These are (1) accumulation, (2) critical periods and (3) effect modification, which are summarised in Fig.2.4. using the example of a hypothesised relationship between forest access levels over the life course and health in later adulthood.

Accumulation model:

1. Strict (e.g. the effect of forest access on health in late adulthood depends on the total level of forest access experienced over the life course):



2. Relaxed (e.g. the effect of forest access on health in late adulthood depends on the level of forest access at each stage of the life course but with childhood and late adulthood having greater influence than early adulthood):

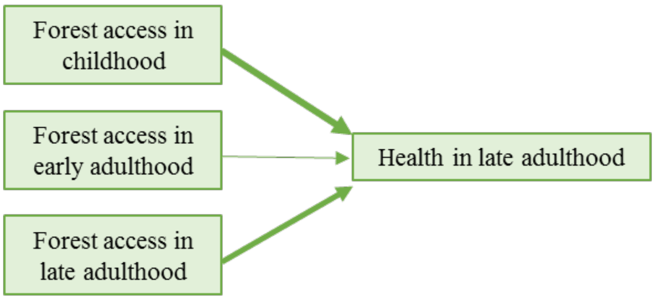
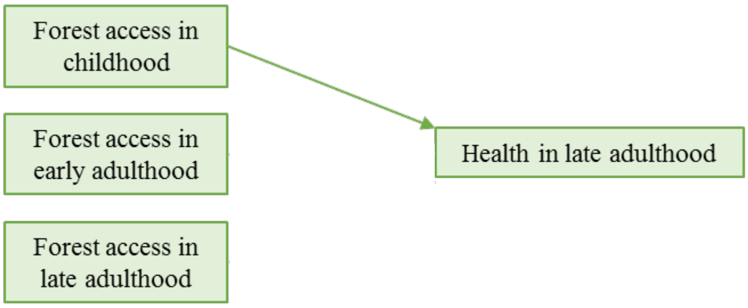


Fig.2.4. Life course models of forest access and health.

Critical period model (e.g. The effect of forest access on health in late adulthood depends on the level of forest access in childhood, regardless of forest access at any other stage in the life course):



Effect modification (e.g. the effect of forest access in childhood on health in late adulthood may be enhanced or diminished depending on level of forest access in early adulthood):

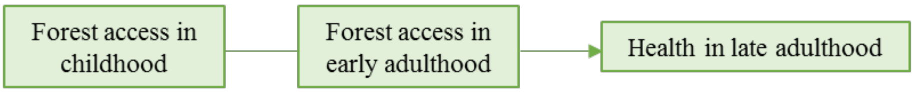


Fig.2.4. continued.

Firstly, the 'accumulation model' proposes that the effects of certain exposures and experiences throughout life can build up over time and influence health later in the life course (Niedzwiedz et al. 2012). There are two suggested mechanisms through which exposures can accumulate and subsequently influence later health. These are known as 'strict' and 'relaxed'. Using the example of forest access, the 'strict' accumulation model would suggest that individuals with higher total levels of forest access throughout life may have better health in late adulthood than those with lower total levels of forest access throughout life. The assumptions of the 'relaxed' accumulation model are slightly different whereby it is suggested that level of forest access at all life stages are related to health in late adulthood but that level of forest access in childhood may contribute more than the other life stages (Kuh et al. 2003; Mishra et al. 2009; Murray et al. 2011; Wadsworth et al. 2007; Ward Thompson et al. 2008).

Secondly, the critical period model proposes that there are particular time windows in which change in an environmental exposure can have protective or detrimental effects for later health independently of exposure levels at other time points (Hallqvist et al. 2004). Using the previous example of forest access, under this model, it could be hypothesised that an individual's level of forest access in childhood predicts health in late adulthood regardless of their level of forest access during other life stages.

Thirdly, the effect modification model would postulate that the effect of forest access in childhood on health in late adulthood may be enhanced or diminished depending on level of forest access in early adulthood. A study based in Edinburgh and the Lothians of Scotland found that greater provision of public parks in childhood was significantly linked to better cognitive ageing in older adults but that provision of parks in early adulthood also modified the relationship (Cherrie et al. 2018).

Studies in the UK also suggest that life course models of health may vary between health outcomes studied and socio-demographic groups including sex and socioeconomic status (Cherrie et al. 2018; Singh-Manoux et al. 2004). The importance of recognising cohort effects which apply to a specific group of people born in the same year or time frame has also been emphasised (Ben-Shlomo & Kuh 2002). Therefore, in order to enhance knowledge about life course models of health and associations with environment, there is a need for studies to explore whether there are potential differences between different cohorts, sociodemographic groups and for different measures of health. Longitudinal data about individuals which contain large sample sizes and a range of health outcomes allow exploration into these questions (Menard 2002). Further advantages of adopting longitudinal research designs for investigations into forests, health and inequalities will now be discussed.

2.6.2 Longitudinal study designs

Longitudinal study designs involve the use of repeated observations of the same individuals over a period of time, as opposed to cross-sectional study designs which explore associations at one specific point in time (Farrington 1991). Use of longitudinal data in exploring relationships between forests, health and inequalities may advance knowledge in several ways. These include distinguishing trends in changes and a better understanding of causal relationships between forest access and health (Menard 2002); and exploration into the range of factors leading to or possibly causing changes in people's access to forests and subsequent health outcomes (Singer & Willett 2003).

In cross-sectional studies, any associations are identified from differences between individuals only, therefore the direction of causal pathways cannot be explored. However, longitudinal data allows examination of both differences between individuals and changes over time within the same individual (Farrington, 1991). Longitudinal data allows a clear time-ordering of events to be established, for example whether a change in an individual's health status between two time points occurs after the individual experiences a change in forest access, which may provide stronger support for a causal relationship between access to forests and health. Furthermore, longitudinal data enables different types of questions about the relationship between forests and health to be investigated. People's trajectories of forest access over a time period can be estimated, allowing investigation into whether people with better forest access trajectories throughout the study period have better health at the end of the study period than those with worse trajectories. Such questions have not been explored in the literature on forests (or green space) and health; however, one place-based example includes a study by Walsemann et al. (2017). This explored whether neighbourhood histories of poverty were associated with psychosocial wellbeing amongst mothers living in California. The study showed that women living in areas with decreasing poverty were less likely to have depressive symptoms than those living in low-poverty areas throughout the study period.

Longitudinal data about people's health is becoming increasingly available through birth cohort studies including Growing Up in Scotland (University of Edinburgh 2018) and the British Birth Cohort Studies (University College London 2018) and surveys such as Understanding Society (University of Essex 2018). However, there are very few longitudinal data sources that capture changes in environment. Two examples come from Scotland where data linkage projects have been possible. The first, as described earlier, explored life course models of park access and cognitive health by digitising and linking historical green space maps to the residential address histories contained in the 1936 Lothian Birth Cohort (Cherrie et al. 2018). This study used a model comparison framework developed by Mishra et al. (2009) in order to identify the most appropriate life course model for describing the relationship between green space access at different time points and cognitive health in older age. The second study linked data on urban green space to census data and administrative birth records for siblings. Findings demonstrated that mothers living in areas with more green space were more likely to have babies with higher birthweights. However, advanced modelling also showed that improvements in a mothers' green space access between births were not linked to improved birthweights between siblings (Richardson et al. 2018).

As a result of the lack of available historical environmental data, little is known about how changes in access to natural environments including forests, may correlate with changes in people's health. Due to this limitation, studies often assume that the environment has not changed during the study period. In one study which examined the relationship between green space and mental health across the life course in Great Britain, the measure of green space was estimated using data from one time point only (Astell-Burt, Mitchell, et al. 2014). A similar study, based in England, on the link between green space and well-being (measured by ratings of life satisfaction) applied land use data from 2005 to all time points studied (White et al. 2013b). Another method to explore changes in potential access environments is to focus on participants in a longitudinal survey who have moved to a new house between time points. In Sweden, researchers examined whether there is a relationship between changes in access to types of nature and changes in mental health status, by only including movers in their sample and using environmental data for one time point only (van den Bosch et al. 2015). In addition to ignoring potential changes in land use, excluding nonmovers from the study sample biases results, therefore the extent to which the findings can be generalised to the population is limited.

2.7 Summary

This chapter has reviewed the current theoretical perspectives and empirical investigations relevant to exploring relationships between forests, health and inequalities. In particular, the chapter has highlighted the need to incorporate life course approaches and historical perspectives, and to also consider the principles underlying the environmental justice framework and socioecological models. These approaches are particularly relevant in Scotland where structural-level factors such as shifts in forestry policies and practices, have shaped geographical and sociodemographic differences in levels of forest access among the population.

As demonstrated in this chapter, empirical evidence which supports relationships between forests and health mainly consists of cross-sectional or experimental studies and has involved the collection of both self-reported and biological measures of health for small samples of individuals at one point in time. Also, so far, research in this field has tended to focus on specific contexts such as evaluating the effects of forest therapy programmes on people with particular illnesses; there have been much fewer studies on the possible health benefits of having good access to forests and on whether forests have a role in addressing public health challenges such as reducing socioeconomic health inequalities. Furthermore, there are several criticisms of the experimental study designs currently adopted. These include lack of attention paid to the effect of attrition on results, the suitability of control groups, factors which may affect the validity of findings including the ‘Rosenthal effect’ whereby participants behave in the way expected given their exposure to the treatment or control conditions (I. Lee et al. 2017; Persaud 2012). Other cited issues include the need for larger study samples with a range of age groups, inclusion of participants diagnosed with specific conditions e.g. clinical depression, the use of both self-reported and biological measures of health, and further critical evaluation of the indicators used. This includes both the particular aspects of health supposedly being measured and the ways in which exposure to forests is captured i.e. through people's actual use of forests or level of potential access based on residential address (I. Lee et al. 2017; Song et al. 2016).

As argued in this chapter and elsewhere, there is a clear need for more longitudinal studies which utilise data about people and their potential access to forests, collected at different time points. Longitudinal data allows exploration into the long-term effects of forests on health; testing of whether there are links between changes in people's access to forests and changes in their health; and may provide further insight to the potential mechanisms through which forests are related to health (Hansen et al. 2017; I. Lee et al. 2017; Song et al. 2016; Meyer & Bürger-Arndt 2014; Markevych et al. 2014).

The following chapter describes the data and measures used in this thesis in order to examine associations between forests, health and inequalities by applying a longitudinal study design.

3 Data and measures

3.1 Introduction

This thesis aims to examine relationships between forest access, health and inequalities in Scotland by adopting a longitudinal approach. This chapter presents the methodological approach used in order to address this overall aim. The chapter is structured in four key sections. Firstly, the data sources used, and methods adopted for creating measures of forest access and estimates of forest use and the linkage of these to the Scottish Longitudinal Study (SLS) will be described. Then an overview of the data included in the SLS and linked administrative health records will be provided. The third section describes how key measures from these data sets were selected and operationalised. Lastly, details of how the study sample was derived are presented, including the extent and handling of missing data.

3.2 Forestry data

3.2.1 Overview

This section describes the development of the forest exposure measures used. This includes the sourcing and cleaning of forest inventory and land cover data to create a longitudinal forest access data set for Scotland; and creating a synthetic estimate of forest use based on nationwide survey data. The processes of verifying these measures and linking them to the SLS are also described.

3.2.2 Creating measures of forest access

In order to explore whether forest exposure is related to different aspects of health over a period of 20 years, it was essential to create a longitudinal forest dataset. The requirements of the data set were as follows:

- To identify forest cover across Scotland at the time of the last three censuses (1991, 2001 and 2011).

- To distinguish those forests which are likely to be accessible to the public for recreational purposes.
- To include measures of access to forests which can be linked to the members of the Scottish Longitudinal Study.

A flowchart summarising the full process for creating the forestry data set and linking to the SLS is shown in Fig.3.1.

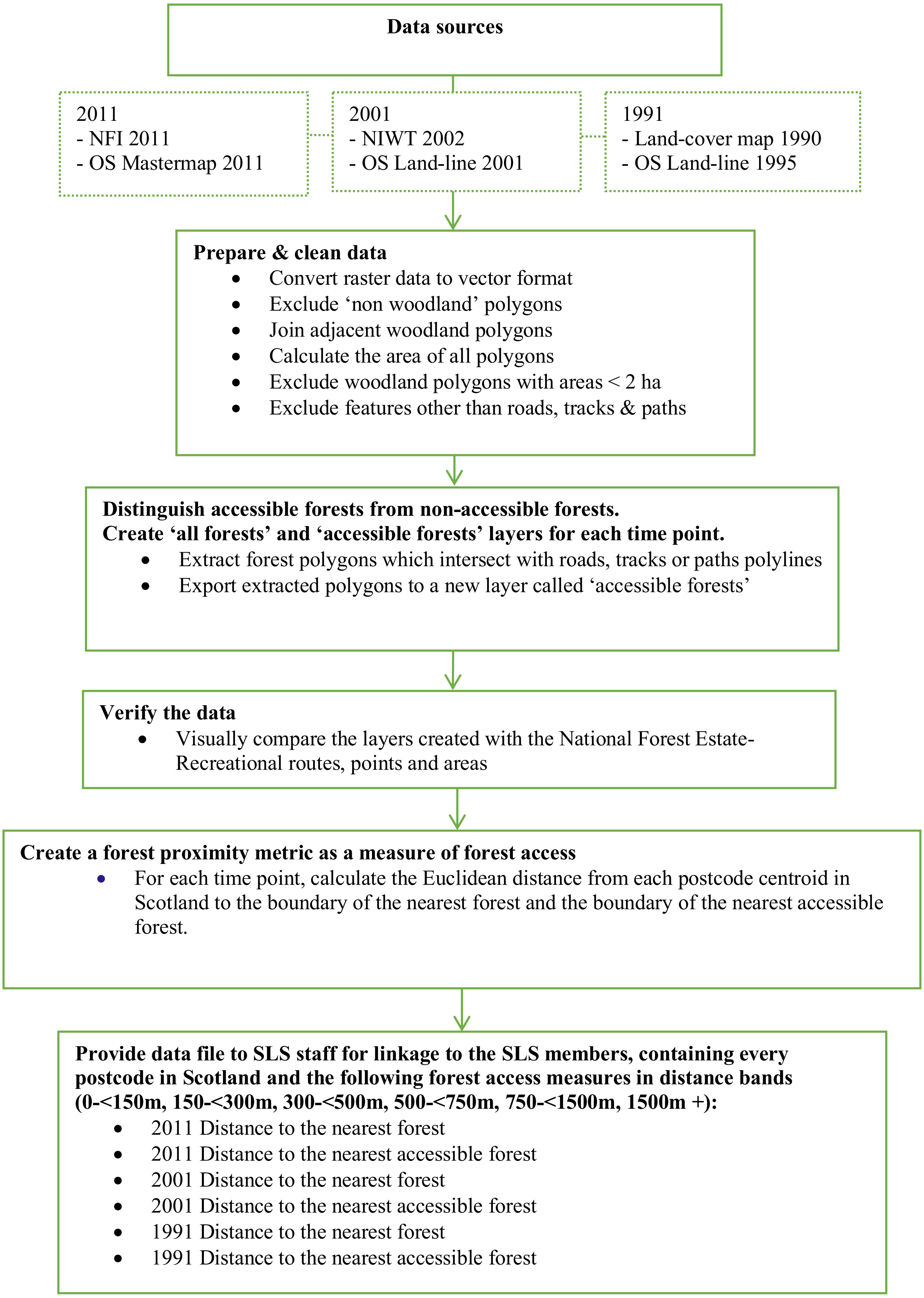


Fig.3.1: Flowchart showing process for creating the forestry data set and linking to the SLS.

3.2.2.1 Data on forest cover

Land Cover Map of Great Britain 1990 (LCMGB)

The Land Cover Map of Great Britain (1990) is the first nationwide digital representation of land cover and was created by the Institute of Terrestrial Ecology (ITE) using satellite information collected in both summer and winter. The map consists of 25m x 25m grid cells and classifies each cell into one of 25 land types, based on satellite images and verified by field observations (Centre for Ecology & Hydrology 1990). The data set was downloaded from the Digimap Collections held by EDINA and was converted from raster format to a polygon shapefile in ArcMap. There are two classifications which identify areas of woodland. These are: '15 - deciduous broadleaved and mixed woodlands' and '16 - conifer and broadleaved ever green trees'. Both classes were selected and extracted from the data set. Adjacent areas of woodland were joined using the 'dissolve' tool and polygons of less than 2ha in size were then excluded. This enabled the data to be comparable with the forestry data contained in the later National Inventory of Woodlands and Trees (NIWT), described below. Also, as highlighted in the previous chapter, 2ha is considered an important threshold in the policy literature surrounding access to natural environments. The threshold is also used by the Forestry Commission for allocating grant funding for forest planting and management.

National Inventory of Woodlands and Trees 2002 (NIWT)

The National Inventory of Woodlands and Trees (NIWT) is a digital map of all areas of woodland equal to or greater than 2ha in size for the whole of Great Britain. In Scotland, the woodland survey was based on the Land Cover Map of Scotland (1988) which was produced from 1:25 000-scale aerial photographic images, collected between 1987 and 1989. The map was last updated by the Forestry Commission in 2002 to contain areas of trees which were either hidden by cloud cover in the photographs or were planted since the recorded photograph date. The NIWT contains data on forest characteristics and classifies woodlands into nine forest types (Smith et al. 2010). The NIWT was downloaded from the Forestry Commission website as an ESRI polygon shape file. Woodland polygons categorised as 'broadleaved', 'conifer' or 'mixed' were extracted from the data set and dissolved so that adjacent woodlands would combine to form the same polygon. The remaining forest types i.e. coppice, felled, ground prepared for planting, shrub and young trees, were not selected for this study as it was thought they would have little or no value to human health, compared to established areas of woodland.

National Inventory for Scotland 2011(NFI)

The Forestry Commission holds an accessible National Forest Inventory (NFI) for Scotland. According to this inventory, in 2011, there were a total of 1,385,000ha of woodland in Scotland, 481,000ha of which were owned by the Forestry Commission and 909,000ha were owned and managed by Councils, private landowners and other organisations (Atkinson & Townsend 2011). Forests included in the data set are at least 0.5ha which allowed the inclusion of very small urban woodlands as well as large forests found in rural areas. The inventory is available to download freely from the Forestry Commission website as a polygon shape file. For the data set to be comparable with the earlier NIWT, dissolved polygons that were less than 2ha in size were removed from the data set. The NFI classifies areas of woodland into 4 Woodland Types. These are 'woodland' (area of established trees), 'low density' (thinned woodland), 'non-woodland' (felled areas, shrub land, open areas and young tress), and 'assumed woodland' (areas recorded as new planting, but no trees identified in aerial photographs). Those areas described as 'woodland' and 'low density' were retained whilst the latter two were discarded as they were unlikely to contain established trees as they were thought to have little or no recreational value.

Ordnance Survey Land-line (1995, 2001) and Mastermap (2011)

Land-line and Mastermap were used to identify accessible forests. These data are routinely produced by Ordnance Survey and have full coverage of Great Britain's public network and private routes extending 100m or more. Spatial data for 1995 (representing access routes in 1991), 2001 and 2011 covering the whole of Scotland were provided by EDINA as File Geodatabase Feature Classes. Line features identified as "roads or tracks" or "paths" were extracted. Then, using the 'select by location' tool in ArcGIS, forest polygons which intersected with roads, paths or tracks were identified as accessible forests and exported into a new layer.

3.2.2.2 Verification

In order to verify that the accessible forests identified above were indeed accessible to the public, the accessible forests layer created was compared to the National Forest Estate (NFE) recreational routes, points and areas data sets. These contain recreational features such as play areas, walking routes and picnic tables for all Forestry Commission owned forests and were last updated in 2014 (Forestry Commission 2017b). This could only be carried out for the 2011 time point as data were not available for the 1991 and 2001 time points.

Using the features contained in the NFE data sets, forest polygons (2011) that intersected with those features were compared with those identified as being accessible. The same 13,442 forest polygons were identified in both the NFE recreational data sets and in the layer classifying accessible forests in 2011. The latter also contained an additional 3,508 woodland polygons. However, it may be possible that these forests contain access routes which are managed by the local authority or other organisation (although the forest is owned by FC); or that the forest is managed mainly for timber production but is still potentially accessible by road or track.

3.2.2.3 Measuring proximity to forests and linkage to the SLS

The study focuses on the influence of people's forest access on different aspects of their health. As discussed in the previous chapter, it has been shown that living in close proximity to forests and other types of green space is a strong predictor of visiting these spaces.

Therefore, a forest proximity metric was used as a measure of forest access. People's proximity to forests were created by calculating the distance from postcode population weighted centroids to the boundary of the nearest forest. Geocoded postcode centroids for 1991, 2001 and 2011, covering the whole of Scotland were sourced from the UK data service (UK Data Service 2012) and mapped in ArcMap. The layers containing the boundaries of every forest in Scotland, and every accessible forest, were also mapped. Using the 'near' tool, the Euclidean distance from the postcode centroids to the nearest forest and nearest accessible forest were calculated in metres, for each time point. Network distance could not be calculated due to historical data suitable for network analysis in ArcGIS not being available for 1991 and 2001. Also, there were no data showing forest access points.

Data files containing the postcodes and corresponding distances were linked to the SLS members using the postcode for place of residence recorded in the 1991, 2001 and 2011 censuses. Due to the potential risk of SLS members' identities being disclosed, postcodes are not released to researchers. Therefore, linkage was completed by SLS staff. Also, to minimise disclosure risk, the forest distance measures were provided as categorical variables rather than continuous. Different ways of categorising the variables were investigated. As discussed in Chapter 2, in earlier work many different thresholds have been recognised as important for determining use of green spaces and for predicting health outcomes. The primary distance bands selected for this study are those used in previous research which explores the psychological impacts of Forestry Commission Scotland's Woods In and Around Towns (WIAT) programme (Silveirinha de Oliveira et al. 2013). These are 0-<150m, 150-<300m, 300-<500m, 500-<750m, 750-<1500m, 1500m +. The selected distance bands reflect earlier findings in the literature regarding threshold distances associated with health outcomes e.g. living within 300m and 500m of forests, and enabled a large enough range of categories for individuals.

3.2.3 Estimating use of forests

As highlighted in Chapter 2, studies often rely on information about where people live in relation to forests and not their actual use or time spent in forests, when measuring exposure and analysing with health outcomes. Unfortunately, information about individuals' health and use of forests is not included in any nationwide dataset for the UK or Scotland. Therefore, insights on the relationship between forests and health at the population-level can only be drawn from estimates of peoples' proximity to forests, based on their residential location and not their actual direct exposure to forests. Without further information on the behaviour of individuals in relation to forests, it is difficult to explore the mechanisms through which forests are related to health. One way of addressing the absence of forest use measures in large-scale data sets such as administrative records and the Scottish Longitudinal Study (SLS) is to create synthetic estimates of forest use for individuals, based on the information in a separate data set.

3.2.3.1 Data source - Scotland's People and Nature Survey

The likelihood of visiting forests was estimated using data from the Scotland's People and Nature Survey (SPANS) which was conducted between March 2013 and February 2014 (TNS 2014b). Data were collected by interview from approximately 1000 adults (aged 16 years or over) each month, generating a total sample size of 12,104 people living in Scotland. Commissioned by Scottish Natural Heritage (SNH), SPANS forms part of the wider Scottish Opinion Survey (SOS) and consists of several sets of questions, with each set added to the SOS on a rotational basis therefore not all questions are asked every month. Questions relating to forest use were asked bi-monthly. Respondents were asked "In the last 12 months, how often on average have you visited forests or woodlands for walks, picnics or other recreation? (More than once per day/Everyday/Several times per week/Once a week/Once or twice a month/Once every 2-3 months/Once or twice/Never)". A total of 4,694 individuals provided responses (TNS 2014c) as shown in Table 3.1. This was recoded into a binary measure of forest use.

Question: In the last 12 months, how often on average have you visited forests or woodlands for walks, picnics or other recreation?		
Responses	**n**	**%**
More than once per day	22	0.47
Every day	192	4.09
Several times per week	360	7.67
Once a week	455	9.69
Once or twice a month	879	18.73
Once every 2-3 months	717	15.27
Once or twice	909	19.37
Never	1,160	24.71
Total	4,694	100.00

Table 3.1: Frequencies of forest use, as measured in SPANS. SPANS 2013/14 was commissioned and managed by Scottish Natural Heritage and funded jointly by Scottish Natural Heritage, Forestry Commission Scotland, Cairngorms National Park Authority and Loch Lomond and the Trossachs National Park Authority.

Potential thresholds considered to create a binary variable included visiting forests weekly, monthly and at least once in the last 12 months. 'At least once a week/less than once a week' was used by Mitchell (2013) to explore physical activity in urban green spaces and mental health outcomes. People who visited forests at least weekly were significantly less likely to have poor mental health than non-users (Cox et al. 2017; Mitchell 2013). Alternatively, 'at least monthly/less than monthly' was identified as a threshold in a study examining frequency of green space visits and self-reported mental health. Scores for measures of psychological wellbeing decreased for those visiting less than monthly (Dallimer et al. 2014). However, a study which identified distinct categories of forest users highlighted similarities in characteristics and perceptions of forests between those who visited monthly and weekly; and those who visited once a year and those who reported that they never visit forests (Ward Thompson et al. 2004). Taking these findings into consideration, a binary variable measuring the likelihood of visiting forests was created where those visiting once a month or more are considered likely to use forests and those visiting less than once a month are not expected to use forests. For sensitivity, binary variables based on weekly use and whether the respondent had ever visited forests in the last 12 months were also created.

3.2.3.2 *Predictor variables*

In order for the synthetic estimate to be applied to SLS members, the variables used to predict forest use must be present in both SPANS and SLS. As described in Chapter 2, previous studies suggest that various demographic and household factors may be related to forest use, including age, socioeconomic status and having children in the household (Morris et al. 2011; Ward Thompson et al. 2005; Schipperijn et al. 2010; Irvine et al. 2013). Other identified factors that are not included in the SLS or SPANS include childhood visits to forests and having a cultural or emotional association with forests (Ward Thompson et al. 2004). The variables suggested in the literature that are present in both SPANS and the SLS which will be considered for creating the measure of forest use include: age, sex, ethnicity, children in the household and housing tenure.

3.2.3.3 Statistical approach

Creating the synthetic estimate

Individuals aged 16 and 17 were excluded from the sample (n=187) so the age range would be the same as for the SLS. The bivariate relationship between each of the selected variables listed above and forest use was tested using the chi square test. For sensitivity, other variables shown to be related to forest use and which were only present in SPANS were also examined: measures of dog ownership and perceptions of the local area. Unfortunately, these variables contained high levels of missing data (>90%) and therefore could not be used in a sensitivity analysis.

All variables tested (age, sex, ethnic origin, children in the household and housing tenure) except sex were found to have a significant correlation with forest use ($p<0.05$). A binary logit model was then used to estimate the likelihood of forest use. All variables were added to the model together. In a fully adjusted model, having children in the household was not significantly associated with forest use so this was dropped from the model. Frequencies for the variables in the final model, and the estimates generated, are shown in Table 3.2. Following the approach adopted by Clemens & Dibben (2014), individuals with missing data in any of the final predictor variables or outcome variable were excluded (n=85), providing a final sample size of 4,609 people.

Variable	**n(%)**	**Visited weekly**	**Visited monthly**	**Visited at least once**
Age group				
(reference: 45-54)	839(18.20)			
18-24	430(9.33)	-0.22	-0.11	-0.24
25-34	703(15.25)	-0.18	-0.05	-0.05
35-44	692(15.01)	-0.67	0.02	0.06
55-64	795(17.25)	**-0.32**	**-0.37**	**-0.66**
65-74	735(15.95)	**-0.32**	**-0.36**	**-0.90**
75+	415(9.00)	**-0.66**	**-0.90**	**-1.39**
Ethnicity				
(reference: white)	4,502(97.68)			
Not white	107(2.32)	**-0.64**	**-1.09**	**-0.93**
Housing tenure				
(reference: owns home)	2,964(63.92)			
Private rented	535(11.61)	-0.23	-0.20	**-0.35**
Social rented	1,070(23.22)	**-0.22**	**-0.42**	**-0.72**
Other	58(1.26)	0.04	0.06	-0.11

*Significant results in bold ($p<0.05$)

Table 3.2: Coefficients estimating likelihood of whether the respondent visited forests weekly, monthly and at least once in the previous 12 months.

Linkage to the SLS

The estimates of forest use generated were converted to log odds then probabilities, following the approach by Scottish Government (2016). Estimates were then created for every combination of the predictor variables and written into a Stata do file. This allowed the estimates to be applied to the SLS members, indicating likelihood of forest use.

3.2.3.4 Validation of estimates

The following steps were taken in order to validate the estimates created. Firstly, different model specifications such as with sex and children in the household added, were compared using Akaike Information Criteria (AIC). AIC is used to assess relative model fit based on the number of parameters in the model whereby models with smaller values of AIC better represent patterns in the data hence indicate better model-fit (Singer & Willett 2003). The final model, containing age, ethnicity and housing tenure was found to have the most appropriate model specification.

Secondly, whether the synthetic forest use estimates were associated with health in the way that actual forest use would be expected to, was tested by applying the 'visited forests at least monthly' estimate to individuals in the Scottish Health Survey (SHS) 2013 (n=4,786). The outcome modelled (binary logistic regression) was whether or not the respondent had a long-term illness. On the other hand, whether or not the participant had eaten fruit the previous day was also tested, as this was not anticipated to be related to forest use. This analysis indicated that people who used forests at least monthly were significantly less likely to have a long-term illness (OR=0.94, 95% CI=0.93-0.95). As expected, forest use was not significantly related to eating fruit (OR=1.00, 95% CI=0.99-1.01). Therefore, these results may suggest that the synthetic forest estimate behaves similarly to an actual forest use measure in relation to health outcomes.

3.3 **Individual-level health data**

3.3.1 Data source criteria

In order to address the thesis objectives, the forest proximity measures were linked to a data set that satisfied two criteria. Firstly, it had to be longitudinal, nationally representative and contain measures of general and mental health for individuals living in Scotland. Ideally the data set would also allow more specific health outcomes to be explored, in particular those that are hypothesised to be related to the natural environment. Secondly, it had to have a large sample size and rich information on individual-level and area-level socioeconomic characteristics so that potential inequalities between social groups could be explored. The data set also had to contain postcode information for place of residence at each time point to enable linkage to forest proximity measures.

3.3.2 Scottish Longitudinal Study

The Scottish Longitudinal Study (SLS) contains census data collected in 1991, 2001 and 2011 for approximately 274,000 individuals living in Scotland (5.3% of the population). Study members were recruited using 20 random birth dates. Administrative records such as vital events (births, marriages and deaths), education and health data can also be linked to the SLS members (SLS-DSU University of Edinburgh 2018b). For each of the three time points, the SLS contains information on individual's general health, socioeconomic position and demographic characteristics. It also contains the study members' postcodes (raw data only accessible to SLS staff) and ecological variables which provide information about the neighbourhoods in which they have lived at each time point including deprivation scores (Feng 2013). As census information is required by law this means that attrition rates are very low which allows a large sample size to be maintained over the 20-year period. As people are lost from the study by death and emigration, they are replaced with those who enter by birth or immigration into Scotland (Hattersley & Boyle 2007).

3.3.3 NHS administrative health data

3.3.3.1 Overview

The following sub-sections describe each of the administrative health data sets that were joined to the SLS for further analysis on specific outcomes. As detailed in the previous chapter, earlier research suggests that engaging with forests improves mental health. This includes reducing symptoms of particular conditions such as anxiety and depression. Administrative health records allow the exploration of specific mental health outcomes (e.g. prescribing of antidepressants) in addition to the general health outcomes contained in the SLS. Furthermore, data on hospital episodes indicates whether the SLS members have received care or treatment as a mental health inpatient or by visiting an outpatient clinic.

3.3.3.2 Prescribing Information System (PIS)

The Prescribing Information System contains all records relating to medicines prescribed by doctors, nurses and dentists within NHS Scotland which were dispensed in community pharmacies. Data includes information about the drugs being prescribed e.g. name, strength and quantity provided; the dates the medicines were prescribed; and details of the prescriber and dispenser. The PIS was initiated in 1993; however, for research purposes, the data set is only available for 2009 onwards due to data quality issues with earlier records (NHS National Services Scotland 2012).

3.3.3.3 Scottish Morbidity Records 04 – Mental Health Inpatient and Day Case dataset (SMR 04)

The Mental Health Inpatient and Day Case dataset contains records of all admissions to psychiatric NHS hospitals in Scotland. Inpatients are defined as those who stay overnight in the hospital whereas day cases require the use of a hospital bed for their treatment but without staying in hospital overnight. Data includes the dates of admission and discharge, diagnoses (the main condition and up to five additional conditions are provided at the time of admission and at discharge) and length of hospital stay. The dataset contains records from 1981 onwards but, due to data quality issues, only records from 1997 onwards are available (ISD Scotland 2018).

3.3.3.4 Scottish Morbidity Records 00 – Outpatient Attendance dataset (SMR 00)

The Outpatients Attendance dataset includes information on all outpatient appointments at Scottish NHS clinics (except for Accident and Emergency and Genito-Urinary Medicine). Outpatients include those who attend an arranged meeting with a specialist clinician in order to seek advice or receive treatment for a particular health issue. The data set includes information on each appointment including the date, the speciality of the clinician seen and the recommended follow-up care. The data set is available from 1997 onwards (Rapson 2010).

3.3.4 Accessing the SLS and NHS health data

The SLS and NHS administrative health data sets contain anonymised individual-level data therefore a number of measures are put in place by the National Records of Scotland to ensure confidentiality. To be granted access to the data, application forms were completed and submitted to the SLS Research Board and the Public Benefit and Privacy Panel for Health and Social Care. These forms detailed the scope of the proposed research and the specific variables needed. As required by the SLS team, a training course in Information Governance was completed by the researcher and SLS Approved Researcher status was attained. An Undertaking Form was signed by the researcher and all members of the supervisory team to show understanding of the confidentiality and security procedures. Once the application forms were approved and the required data extracted, the data were accessed on a stand-alone computer in the SLS safe setting at the National Records of Scotland office in Edinburgh. Before any data and results were taken out of the safe setting to discuss within the supervisory team or present at conferences for example, they were checked and approved by the SLS team in line with the SLS Disclosure Control Protocol. Further details about the SLS data access arrangements are found on their website: https://sls.lscs.ac.uk/

3.4 **Selection and operationalisation of key variables**

3.4.1 Measures derived from the SLS

Several health outcome measures are examined in this thesis. Census measures included whether or not the SLS member had a long-term illness, had a mental health condition, and a self-assessment of general health. The actual questions asked in the census and possible responses are summarised in Table 3.3

Long-term illness

The measure for long term illness was the only health-related question included in all three censuses. This was used as a measure of general health in chapter 7 which explored changes in people's health between the three time points and changes in forest proximity. The measure from the 2011 census, was recoded into binary form with 'Yes, limited a lot' and 'Yes, limited a little' combined into one category. Census information on long-term illness is a reliable indicator of need for health services and recreational facilities. It is also regularly used in policy environments for monitoring progress in improving public health (Office for National Statistics 2010). Due to its utility in policy and because long-term illness was the only measure of general health present at each of the three study points, it was considered an appropriate outcome of interest for this study.

Self-reported general health

In the initial cross-sectional analyses (forming part of chapter 5), the self-reported general health measure was explored. Following a similar approach in other studies (Maas et al. 2006; Moskowitz et al. 2013; Young et al. 2010), the responses to the general health question were dichotomised with 'very good' and 'good' combined into one category; and 'fair', 'poor' and 'very poor' combined to form the second category. Due to this question only being asked in the 2001 and 2011 censuses and there being changes to the coding scheme, it was not appropriate for longitudinal analyses in this study which examines changes in health between all three of the censuses.

Mental health condition

In the 2011 census only, respondents were asked to indicate the nature of any health conditions which have lasted or expected to last for at least 12 months, which included an option for 'mental health condition'. The measures derived from this question are provided as binary variables, indicating whether the SLS member reported having any of the conditions provided: 1) has a mental health condition; 2) does not have a mental health condition.

3.4.2 Measures derived from administrative health data

Four binary measures which provide information about different aspects of mental health from 2011 to 2016, were derived from the administrative health data sets described in section 3.3.3. This allowed investigation into whether patterns of forest proximity throughout the study period influenced particular aspects of mental health at the end of the study period. Four outcome variables were derived from the administrative health data sets as summarised in Table 3.4. These were whether between 2011 and 2016, the SLS member was:

- Prescribed antidepressants
- Prescribed anxiolytics
- Admitted as an inpatient to a mental health hospital
- Attended an outpatient clinic for a mental health issue.

For sensitivity, a combined measure indicating whether or not the SLS member was prescribed anxiolytics or antidepressants between 2011 and 2016 was also created as some types of antidepressants such as selective serotonin reuptake inhibitors (SSRIs), are prescribed for the treatment of depression, anxiety and other mental health conditions (NHS National Services Scotland 2017b). Furthermore, amitriptyline, another type of antidepressant, can also be used to treat other conditions such as migraines and chronic pain at doses less than 30mg per day, as well as depression which tends to be prescribed at higher doses (NHS National Services Scotland 2014). Therefore, there is a risk of misclassifying SLS members when using this data. In order to address this, exploratory analysis was also conducted with individuals who were prescribed amitriptyline on doses less than 30mg per day, classified as not receiving antidepressants.

Each of the three administrative data sets used in this study were provided with multiple records per individual SLS member i.e. one record per hospital episode or per medicine prescribed. Once the required records were extracted, the data sets were reduced to single records per individual and linked to the SLS, using the SLS identification number which was present in both data sets.

Prescriptions for antidepressants and anxiolytics were distinguished using the British National Formulary (BNF) sub-section code (4.1.2. for anxiolytics and 4.3.1-4 for antidepressants) (NHS National Services Scotland 2012). Patients who attended an outpatient clinic for a mental health issue were distinguished using the ‘speciality classification’ variable. This variable provides information about the specialism of the clinician seen by the patient. There is a total of 62 different specialities in the data set. For this study, only those records with specialisms relating to mental health were extracted. These were General Psychiatry, Psychiatry of Old Age and Psychotherapy (Rapson 2010). As the Mental Health Inpatient and Day Case dataset only contained admissions for mental health conditions, all records were extracted from the data set.

Measure of health	Census questions 1991	2001	2011
Long term illness	Do you have any long-term illness, health problem or handicap which limits your daily activities or the work you can do? Include problems that are due to old age. 1) Yes, I have a health problem which limits activities 2) I have no such health problem	Do you have any long-term illness, health problem or handicap which limits your daily activities or the work you can do? Include problems that are due to old age. 1) Yes 2) No	Are your day-to-day activities limited because of a health problem or disability which has lasted, or is expected to last, at least 12 months? Include problems related to old age. 1) Yes, limited a lot 2) Yes, limited a little 3) No
General health		Over the past 12 months would you say your health on the whole has been: 1) Good? 2) Fairly good? 3) Not good?	How is your health in general? 1) Very good 2) Good 3) Fair 4) Bad 5) Very bad
Mental health			Do you have any of the following conditions which have lasted, or expected to last, at least 12 months? Tick all that apply 1) Deafness or partial hearing loss 2) Blindness or partial sight loss 3) Learning disability (for example, Down's Syndrome) 4) Learning difficulty (for example, dyslexia) 5) Developmental disorder (for example, Autistic Spectrum Disorder or Asperger's Syndrome) 6) Physical disability 7) Mental health condition 8) Long-term illness, disease or condition 9) Other condition, please write in 10) No condition

Table 3.3: All health-related questions included in the 1991, 2001 and 2011 Scottish censuses.

Administrative health data sets	Measures derived
Prescribing Information System	Prescribed antidepressants 2011-2016 (Yes/No) Prescribed anxiolytics 2011-2016 (Yes/No) Prescribed antidepressants or anxiolytics 2011-2016 (Yes/No)
Scottish Morbidity Records 04 – Mental Health Inpatient and Day Case dataset (SMR 04)	Admitted to a mental health hospital 2011-2016 (Yes/No)
Scottish Morbidity Records 00 – Outpatient Attendance dataset (SMR 00)	Attended outpatient clinic for a mental health issue 2011-2016 (Yes/No)

Table 3.4: Measures derived from administrative health data sets.

3.4.3 Potential confounders

This section describes the variables considered as potential confounders of the relationship between forests and health, and the data preparation steps undertaken.

3.4.3.1 Demographic variables

Sex, age, ethnicity and children in the household

As discussed in Chapter 2, studies suggest that the health benefits of forests may be unevenly shared between men and women (Richardson & Mitchell 2010). Therefore, sex is considered a potential confounder in the study, due to the close connection to patterns of health and suggested link to forest use. In the SLS, sex is recorded as a binary variable (male or female). Also highlighted in the previous chapter is the importance of age in determining use of forests, with people over the age of 45 being the most likely to visit forests (Forestry Commission 2013) and significant health benefits of forests being found only among middle-aged study participants (Sawa et al. 2011). Again, there is an obvious link between age and illness, with older people more likely to have health issues, (Mavandadi et al. 2007) and so it was important to include age as a confounding factor. For this study, age was categorised into 4 groups. These were (age in 1991): 18-29, 30-44, 45-54, 55+. The cut off points for the age groups were restricted by the data distribution. Ideally, the group aged 55+ in 1991 would have been further classified e.g. 55-74, 75+, as the group is likely to be heterogeneous in terms of health. However, initial exploratory analysis indicated that there were too few cases in each category for conducting stratified analyses. As explained fully in section 3.5, the study sample only contained those who were present in all three censuses and aged at least 18 years in 1991, therefore the sample is relatively young at this initial date, and ages throughout the study period.

In this study, the data for ethnicity is as reported at the time of the 1991 census. Respondents were asked to provide their ethnic group by ticking the appropriate option. Respondents could choose between White, Black-Caribbean, Black-African, Black-Other, Indian, Pakistani, Bangladeshi, Chinese, or any other ethnic group. Respondents also had the option to describe their ancestry. In the SLS, the variable is coded with 35 different categories. However, due to the relatively low ethnic diversity in Scotland, the variable was recoded as binary (white/not white) to enable sufficient category numbers for analyses.

Also accounted for is whether the SLS member lived with children in the household, as this has been shown to influence the chances of visiting local green spaces (Irvine et al. 2013) and is potentially linked to mental health (Helbig et al. 2006). Therefore a binary variable indicating this was derived for each time point i.e. children present in the household (yes/no).

3.4.3.2 Socioeconomic variables

The SLS offers a variety of indicators that may be used as measures of socioeconomic status (SES). For this study it was important to identify the particular aspects of SES that were most closely linked to the relationship between forests and health and therefore can be treated as potential confounders. Problems with the way in which SES is controlled for in health research have been discussed and critiqued. SES is widely recognised as a complex and multifaceted construct made up of psychosocial and material elements (Grundy & Holt 2001) and therefore cannot be captured in a single indicator (Braveman et al. 2005a). It has been suggested that variables measuring SES should have meaning for the particular population groups and health outcomes being examined (Shavers 2007) and reflect the hypothesised causal mechanisms through which the particular SES measure is related to the variables of interest (Macintyre et al. 2003). It is also recognised that accurate measurement of SES for individuals is not always possible and that researchers are often limited by the availability and quality of data (Braveman et al. 2005). Therefore, a combination of individual, household and/or area-level measures which capture different elements of socioeconomic position should be considered. It has also been suggested that education or social class paired with a household or area-level measure of material deprivation is appropriate for investigating health and health inequalities among older age groups in particular (Grundy and Holt, 2001). In this study, all measures of SES considered are described below. For the reasons outlined, it was decided to measure socioeconomic status using the SLS member's highest level of education and housing tenure. These were provided for each of the three study time points.

Highest-level education

Education is one of the most widely used measures of SES in health research. An individual's education captures potential earnings and occupational opportunities (Braveman et al. 2005). It has also been suggested that education might also be related to health through health behaviours, with those who are more educated more likely to engage in health supporting activities (Lynch et al. 1997). Furthermore, as education is normally completed in early adulthood, highest-level qualification is particularly useful for the current study as the study population is aged at least 38 years at the last study time point and it is reasonable to expect study members to have completed their education by this age.

The highest-level educational qualification held by the SLS member is provided for each time point. For 2001 and 2011, variables are provided with five categories. These are:

- No qualifications (0)
- Standard grade/GCSE/CSE/GSVQ/SVQ Level 1 or 2/SCOTVEC module etc. (1)
- Higher grade/CSYS/GSVQ/SVQ Level 3/ONC/OND etc. (2)
- HNC/HND/SVQ level 4 or 5 etc. (3)

- First degree/higher degree/Professional qualifications (4)

In the 1991 census, the question regarding highest-level education only asked about post-school qualifications and was therefore coded into fewer categories, indicating whether or not the respondent had a degree (2), a higher qualification other than a degree (1), or none (0). To maintain consistency across time points, highest-level education in 2001 and 2011 was also recoded into the same format.

Housing tenure

Household tenure is often used as a measure of material deprivation (Macintyre et al. 2003) and due to the home ownership category, also potentially captures financial assets and wealth. In the 2001 and 2011 censuses, respondents were asked whether they owned or rented their accommodation and could provide one of the following answers:

- Owns outright
- Owns with a mortgage or loan
- Part owns and part rents (shared ownership)
- Rents (with or without housing benefit)
- Lives here rent free

If renting, respondents were then asked who their landlord was which helped distinguish those who rented privately i.e. from a private landlord, letting agency, employer, relative or friend, and those who rented socially i.e. from their local authority, a housing association or registered social landlord. In the 1991 census, a similar question with regards to housing tenure was asked with respondents asked to specify whether they rent or own their accommodation and the arrangement for this. However, the option for shared ownership was not available. In the SLS, the housing tenure variables were derived from the two questions about tenure and nature of the landlord. These variables were recoded as summarised in Table 3.5. Those who lived rent free were in small numbers and were grouped with private renters. In the census questionnaire, those who reported living rent free were still asked who their landlord was, but this was not specified by the coding of the derived variable. It was thought that people living rent free would have been able to do so through the social support provided by and the wealth of a close friend or relative, but do not have enough financial resources to own their home. Therefore, for psychosocial reasons they were considered to be more similar to private renters than social renters.

1991 census variable coding	2001 census variable coding	2011 census variable coding	Recoded variable used in analyses
1.Owner occupier – mortgage or loan 2.Owner occupier – outright	1.Owner occupier – mortgage or loan 2.Owner occupier – outright 3.Owned - Shared ownership	1.Owner occupier – mortgage or loan 2.Owner occupier – outright 3.Owned - Shared ownership	1.Owner
3.Scottish special housing association/Scottish homes 4.Local Authority (Council) 5.New Town Corporation 6.Housing Association or charitable trust	4.Social rented: Rented from council (or Scottish Homes) 5.Social rented: Registered Social Landlord or Housing Association	4.Social rented: Rented from council 5.Social rented: Registered Social Landlord or Housing Association	2.Social rented
7.Private landlord - furnished 8.Private landlord - unfurnished 9.With job; farm; shop or other business	6.Private rented: Private landlord or letting agency 7.Private rented: Employer of a household member 8.Private rented: Relative or friend of a household member 9.Private rented: Other 10.Lives rent free	6.Private rented: Private landlord or letting agency 7.Private rented: Employer of a household member 8.Private rented: Relative or friend of a household member 9.Private rented: Other 10.Lives rent free	3.Private rented

Table 3.5: Recoding of housing tenure variables.

Other SES measures considered: Economic activity, The National Statistics Socio-economic Classification (NS-SEC) & Income

The census measures economic activity by asking whether the respondent was employed or self-employed; working hours; and reasons for being unemployed e.g. student, long-term sick or disabled, retired and looking after home/family. This variable was considered unsuitable for measuring SES in this study because it does not capture social hierarchy within those who are employed and those who are retired. Therefore, important psychosocial elements of SES relating to health might be ignored. Also, due to the ‘long-term sick or disabled' category, it is problematic for modelling with health outcomes. Furthermore, it is not completely comparable between the censuses due to differences in wording in the census questionnaire (SLS-DSU University of Edinburgh 2018a).

Current main job and a brief description of duties was also asked in the last three censuses. If not currently working, respondents were instructed to provide the details of their last main job, which means retirees were also able to be included. In the SLS, information on occupation is coded in line with the NS-SEC. However, it was decided not to use occupation-based measures as they are not so helpful for capturing the SES of certain groups including women whose work is more likely to be based at home for example raising a family, people working in casual or informal jobs, and retirees (Galobardes et al. 2006).

A synthetic measure of income based on Standard Occupational Classification (SOC) created by Clemens & Dibben (2014) was also considered but was found to have several disadvantages for this study. Firstly, the measure is only currently available for the 1991 and 2001 census; secondly, income can only be estimated for those who are in employment. Whilst Clemens & Dibben (2014) suggest that income can be estimated for these groups based on standard welfare payments or a pre-retirement occupation if recorded, it was decided that this could not be done robustly without further modelling which was beyond the scope of the thesis.

3.4.3.3 Area-level deprivation measure - Carstairs index

An area-level measure of deprivation was required in order to assess whether deprived and affluent neighbourhoods have different levels of forest proximity. The Carstairs index was chosen as this was the only area-level deprivation measure available for each of the time points used in this study. The index was created from four census indicators aggregated at the postcode sector level, for which there were 978 in Scotland, at the time of the 2011 census (NHS National Services Scotland 2017a). These indicators are: (1) lack of car ownership (2) low occupational social class (3) overcrowded households; and (4) male unemployment (ISD Scotland 2010). The Carstairs index was not used as a covariate in the current study as aspects of socioeconomic status and material deprivation are already controlled for using individual-level (highest-level education) and household-level indicators (housing tenure). Controlling for these elements at the neighbourhood-level may result in over-adjusting analysis models as highlighted in previous studies (Murray et al. 2013; Pearce et al. 2015).

3.4.3.4 Environmental measures

Coastal proximity

Previous longitudinal and cross-sectional studies have shown that living closer to the coast is linked to better general and mental health (Wheeler et al. 2012; White et al. 2013a). Exploratory analysis in this study also showed an inverse relationship between forest proximity and coastal proximity, with those in the sample living >1500m from forests tending to be located very close to the coastline. Coastal proximity in distance bands (<1km; >1-5km; >5-20km; >20km), similar to those used in Wheeler et al. (2012), was added to regression models as a confounder. Coastal proximity for 1991, 2001 and 2011 was calculated and linked to the SLS members using the same method used for measuring distance to the nearest forests, as described in section 3.2. i.e. using functions in ArcGIS to calculate Euclidean distance from postcode centroid to the nearest point on the British coastline.

Urban rural classification

The Scottish Government urban rural classification was used to control for rurality and to explore differences in the relationship between forests and health for those living in urban and rural areas. The 2-fold classification was used instead of the 6-fold or 8-fold version of the classification to enable large enough categories for the analysis concerning the SLS sample and health outcomes (Scottish Government 2012). Initial exploratory analysis showed very few SLS members living in remote rural areas who were classed as 'non-white'. For the analysis investigating forest access only (Chapter 4), the 6-fold version was used to enable a more fine-grained examination. The relationship between the two versions and definitions for each of the categories, are shown in Table 3.6. Urban rural classification is provided in the SLS at the output area-level. In Scotland, output areas are the smallest geography for which census data is available and each contain between 20 and 77 households (Scottish Government 2013).

2-fold	6-fold
Urban areas - Settlements of 3,000 people or more	Large Urban Areas - Settlements of 125,000 or more people. Other urban areas - Settlements of 10,000 to 124,999 people. Accessible small towns - Settlements of 3,000 to 9,999 people and within 30 minute drive of a settlement of 10,000 or more Remote small towns - Settlements of 3,000 to 9,999 people and with a drive time of over 30 minutes to a settlement of 10,000 or more.
Rural areas - Settlements of less than 3,000 people	Accessible rural - Areas with a population of less than 3,000 people, and within a 30 minute drive time of a settlement of 10,000 or more. Remote rural - Areas with a population of less than 3,000 people, and with a drive time of over 30 minutes to a settlement of 10,000 or more.

Table 3.6: Scottish Government urban rural classifications.

FCS conservancy regions

The current study aimed to examine the ways in which forest access varied between different regions of Scotland. As the findings will be of particular interest to Forestry Commission Scotland (FCS) who are committed to improving access to forests across the country, the FCS conservancy boundaries were used to identify policy relevant regions. These were downloaded as an ESRI shape file from the Forestry Commission website and linked to all postcodes in Scotland with distance to the nearest forest attached (as explained in section 3.2). Across Scotland, there are five conservancies (Central Scotland, South Scotland, Perth & Argyll, Highlands & Islands and Grampian) which are shown in the map in Fig.3.2. In Chapter 4, levels of forest access are compared between these five regions across the three study time points.

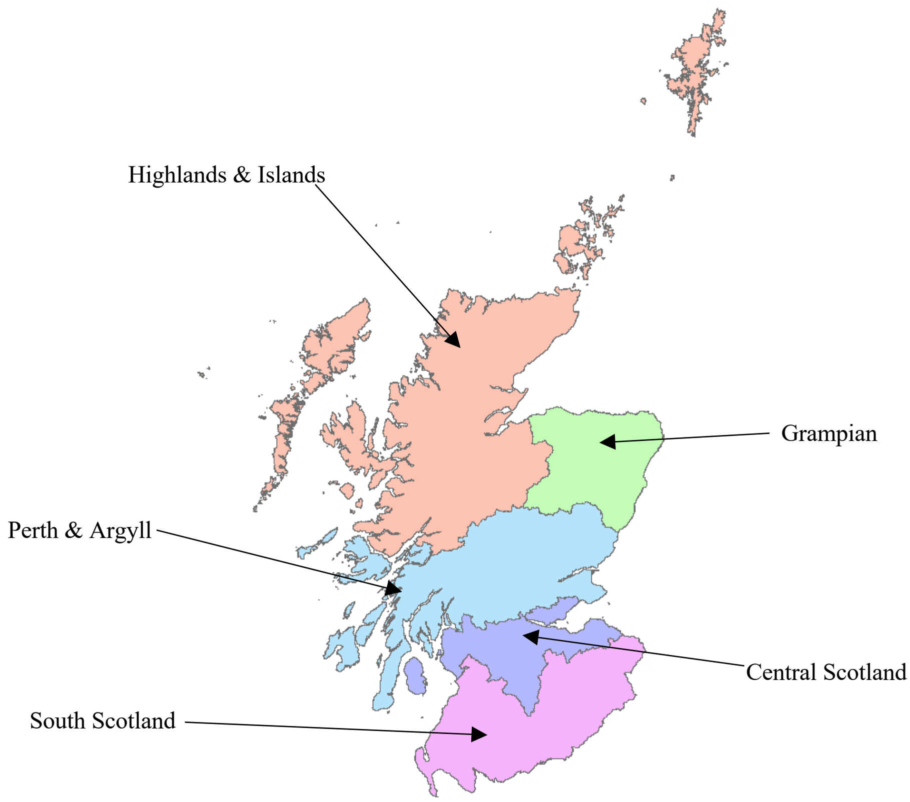


Fig 3.2: Map showing FCS regions.

3.5 **Study sample**

For this study, only those individuals who were present in the 1991, 2001 and 2011 censuses and aged 18+ in 1991 were included in the sample which provided data on 113,171 people. This allowed changes in forest access and changes in health to be examined. It also allowed cumulative effects and critical periods to be assessed. As the SLS covers a 20-year period and not the full life course, it was decided to concentrate on adult years only and assess mental health outcomes later in life. Due to the fact that the amount of prescriptions for antidepressants and anxiolytics is highest for those who are middle aged (40-60 years old) (NHS National Services Scotland 2017b); and the amount of mental health hospital admissions is highest for middle aged and older adults (NHS National Services Scotland 2016), it was decided to focus on those who would be approaching these life stages at the time of the last census.

The flowchart in Fig.3.3 summarises how the final sample was derived from the original SLS extract provided (n=113,171). Residents of communal establishments and those who had missing data were removed from the sample. This gave a sample size of 99,834 people. The extent of and approach to handling missing data are described in section 3.5.2.

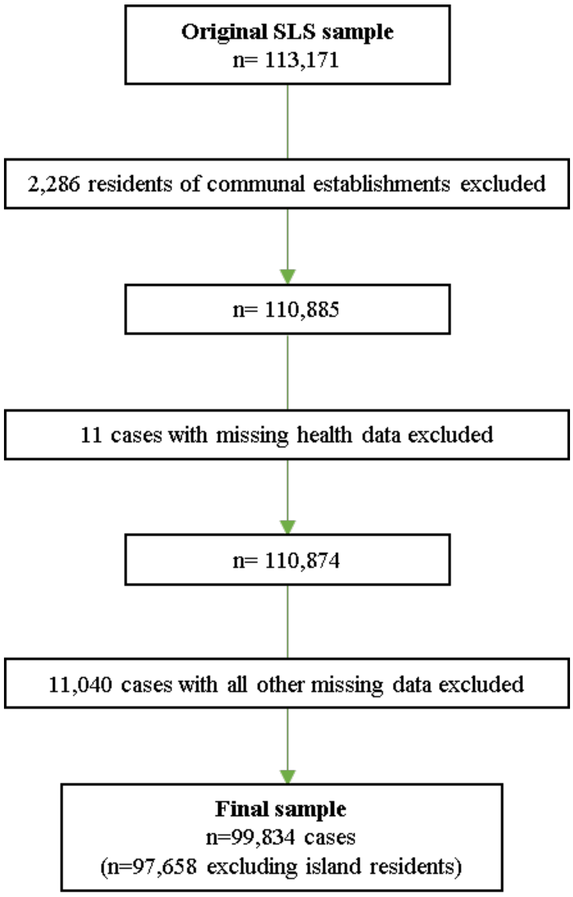


Fig 3.3: Flowchart summarising the sample exclusion criteria

3.5.1 Residents of communal establishments

The study sample excluded individuals who had lived in communal establishments at any time in the study period. Communal establishments are facilities which provide managed residential accommodation and includes prisons, large hospitals and hotels. In the census, an individual is recorded as a communal resident if they have lived in the establishment for at least six months and do not have another usual address recorded (National Records of Scotland 2018a). Communal residents have missing information for household data as this is not collected from them. This includes housing tenure and whether there are children in the household, both of which are covariates used in the analysis. Other studies using the SLS and focusing on health outcomes have also removed communal residents from the sample for this reason (Popham & Boyle 2011; Ralston et al. 2016).

3.5.2 Missing data

This section describes how missing data was handled in the analysis. Due to the variables being derived from routinely collected administrative records and the census, the completion of which is a legal obligation, there was a relatively small amount of missing data present in the sample. Also, missing data and data discrepancies in 2011 were previously imputed before linked to the SLS. Missing data were investigated and identified as one of three types: missing completely at random (MCAR) where the missingness is not due to unobserved and observed factors; missing at random (MAR) where missingness is dependent on only the observed factors; or missing not at random (MNAR) where missingness is dependent on the unobserved factors (Twisk 2013). Table 3.7 shows the proportion of missing observations for the variables used. For those measures derived from administrative health records, there was no missing data.

	Percentage of missing data		
SLS variables with missing data	**1991**	**2001**	**2011**
Long term limiting illness	-	2.51	-
Highest-level education	3.38	2.71	-
Housing tenure	-	1.89	-
Carstairs deprivation quintile	-	0.01	-

Table 3.7: Proportions of missing data in the SLS sample.

For each variable with missing data, the relationship between the missing observation and earlier observation was investigated using chi-square tests. Secondly, the relationship between missing observations and other covariates was investigated using the same statistical technique. Then, the sample was divided into two groups; those without missing data and those with missing data at one or more of the three time points. Any significant associations between variables used in the analysis and having missing data were then identified.

All variables tested were found to be significantly related to 'missingness' in bivariate analyses. However, age had a stronger effect size (V=0.16), with people aged 65+ in 2001 having the highest proportion of missing data (20.5%). This is the case for many data sets possibly because older people are more likely to make mistakes or miss questions when completing questionnaire forms (Hardy et al. 2009). Therefore as the missing data are related to the observed data for another variable, this suggests that the data is missing at random (MAR) (Ibrahim & Molenberghs 2009).

Furthermore, following the approach adopted by Shortt et al. (2014) three versions of the initial exploratory cross-sectional analyses (with all health outcomes studied) were conducted. First of all, models were run with only those in the sample who had complete data. Secondly, the same analysis was run with missing data included as a category in each of the affected variables. Lastly, the models were run with imputed data. For all variables with missing data, ten data sets were imputed by chained equations using the 'mi' suite of functions in Stata. As advised in Bartlett & Carpenter (2013) all variables featuring in final models were included in the imputation model. The estimates produced by the three sets of models were compared. There were no differences in the significance of the estimates between those models with complete case analysis and those where 'missing' was included as an extra category. There were negligible differences (<0.1) in magnitude. The imputed data sets produced some different results. However, as there were minimal changes to the estimates from when those with missing data were excluded from the sample, this indicates that the complete case analysis was not biased. Due to the small proportion of missing data in the sample and the absence of any significant change to the estimates produced when those with missing data were removed, it was decided that imputing the missing values was not required.

3.5.3 Island residents

In Scotland, there are 93 inhabited islands which form 4 main groups. These include the Orkney and Shetland islands, and the Inner and Outer Hebrides. At the time of the 2011 census there was a total of 103,700 people living on islands which is 2% of the Scottish population (National Records of Scotland 2015). Census results show that the composition of island populations tends to be different from that of mainland populations. On average, island residents are older and healthier than those living in the rest of Scotland. The labour market is also different as there is a higher proportion of people working part-time or self-employed and a lower proportion working in professional roles (National Records of Scotland 2015). It has also been suggested that socioeconomic health inequalities are narrower on islands and that the protective effect of high socioeconomic position is reduced or even reversed, possibly due to higher levels of social capital and integration found among island communities (Clemens n.d.). In terms of forestry, areas of woodland are sparse, with just 4.5% of the country's forests found on the islands which are mostly on the Hebrides. Initial exploratory analysis of the NFI 2011 showed that there are just 82ha of woodland on the Orkney Islands and none on the Shetland Islands. For many of the island postcodes the nearest forest was found to be on the mainland or on a neighbouring island with access to them being by ferry or plane. For those living in the Shetlands and Outer Hebrides in particular, distance to the nearest forest was in some cases over 200km. Due to the distinct disparities in the composition of the population; the different relationship between socioeconomic position and health; and lack of practically accessible forests, the first section of analyses in Chapter 4 was conducted with and without island residents in the sample.

3.6 Summary

This chapter has described the data sources used, measures derived, and all the necessary data preparation undertaken to investigate the thesis objectives. The statistical techniques applied and findings of the first set of empirical analyses are discussed in the following chapter.

4 Public access to forests in Scotland and environmental justice

4.1 Introduction

As discussed in Chapter 2, previous cross-sectional studies on cases of environmental injustice in the US and Europe have discovered uneven distributions of urban green spaces, with the most affluent communities tending to have the best access and people living in the most deprived areas benefiting the least. However, this issue has not yet been examined in relation to the distribution of forests. Furthermore, the potential role of historical forestry policies and practices in shaping the subsequent geography of forests has not been considered within a longitudinal and empirical investigation, nor through the lens of recognition and procedural processes of environmental injustice. This chapter enhances the current evidence by exploring the ways in which forest access may have changed for the population of Scotland between 1991, 2001 and 2011. With a particular focus on inequalities in forest access within Scotland, the analysis also provides insight into differential changes in forest access between deprived and affluent areas. Such evidence would provide an indication of whether forest distribution has contributed or not to environmental injustice.

The specific aim and research questions addressed were:

To assess changes in the socio-spatial distribution of forests in Scotland between 1991, 2001 and 2011.

- How has the geographical extent of and access to forests changed over this period?
- How have changes in forest access varied between: deprived and affluent neighbourhoods; different parts of Scotland; and urban and rural areas?

The chapter consists of two main sections. Firstly, the analytical approach and statistical techniques applied in order to investigate the above questions are described. Then the results of the analyses are presented.

4.2 **Analysis plan**

4.2.1 Comparing levels of public access to forests in 1991, 2001 and 2011

The area in hectares (ha) of all forests in Scotland and measures of people's potential access to forests was examined by using the information contained in the forest dataset created (as described in section 3.2). This included the Euclidean distance from every postcode centroid in Scotland to the nearest forest and nearest accessible forest in 1991, 2001 and 2011. Taking into account that the population at every postcode in Scotland would vary with some postcodes having no residents, postcodes were weighted by population size (using the 'iweight' command in Stata), giving greater importance to those with higher populations. For each time point, population-weighted mean distances were calculated which indicated the proximity to forests for Scotland as a whole and how proximity differed between the time points. Results are provided for the analysis with population size accounted for as this was considered more relevant for addressing the objectives and overarching aim of the thesis which are concerned with people's access to forests rather than provision.

For sensitivity, population-weighted mean distances were generated with and without island postcodes in the sample. As explained in Chapter 3, island communities may have exceptionally poor access to forests, compared to those on the mainland, due to there being no forests on some of the island groups.

4.2.2 Modelling change in access to forests

For this section of analysis only, an alternative forest data set with consistent postcode boundaries over time was created to enable the amount of change in forest proximity within postcode areas to be estimated. To ensure consistent geographical boundaries over time, only the 2001 postcode centroids were used to calculate distance to the nearest forest at each time point i.e. distance from 2001 postcode to nearest forest in 1991, distance from 2001 postcode to nearest forest in 2001, and distance from 2001 postcode to nearest forest in 2011.

Mixed-effects (or multilevel) linear regression models were used to explore the changes in distance to the nearest forest. Mixed-effects models are a less crude way of determining the amount and direction of change as they take all data into consideration, not just the mean. They are an extended version of MANOVA and take into account the grouping of individual measurements within cases. The models therefore allow changes within the same postcode areas as well as between postcode areas to be investigated. The coefficients generated by the model can therefore be interpreted as both 'within' and 'between' change (Twisk 2013).

Models were run with a random intercept only which allowed each case to have its own intercept (Ployhart & Vandenberg 2009). A likelihood ratio test was used to assess whether adding a random slope to the model (allowing the slope to vary between cases) was necessary (Torres-Reyna n.d.). The result of this test was insignificant ($p>0.05$) which suggested that the relationship between distance to the nearest forest and time was best analysed using a model with a random intercept only. Models were run initially with each of the forest proximity variables as the outcomes and year as the exposure variable (where year was a categorical variable with 1991 as the reference category). The postcode population size was then added to the model as a covariate to control for population change as it was hypothesised that areas which have experienced change in forest proximity may also have experienced population change for example, forests on the edge of urban areas may have been lost due to housing developments. This first set of models estimated the amount of change in forest proximity between 1991 and 2001 for the whole of Scotland. Models were repeated with 2001 as the reference category to estimate differences over time between 2001 and 2011.

4.2.3 Differences in forest access by area-level deprivation, urban rural classification and geographical region

In order to assess differences in forest access between time points and in deprived and affluent areas and to potentially identify evidence of an environmental justice concern, population-weighted distance means, and mixed-effects models were stratified by Carstairs deprivation index (quintiles). Inequalities in forest access at each time point were examined by calculating the quintile ratio between the most deprived and least deprived area. This indicated whether or not relative inequalities in forest access had reduced between the three time points. The ratio was also calculated separately for urban and rural areas when island postcodes were excluded.

Population-weighted distance means, and mixed-effects models were also stratified by the Scottish Government urban rural classification (6-fold) and FCS conservancy regions (Central Scotland, South Scotland, Perth and Argyll, Highlands and Islands, and Grampian). Wald tests were used to formally assess whether changes in forest access over time varied significantly between areas.

4.3 Results

4.3.1 Scotland's forests

Findings showed that the amount of forestry in Scotland increased over the study period (Fig. 4.1). In 1991, the total amount of forest cover was 523,972ha. This increased to 818,843ha in 2001 and to 1,092,503ha in 2011. The amount of accessible forests also increased throughout but with less change occurring between 2001 and 2011.

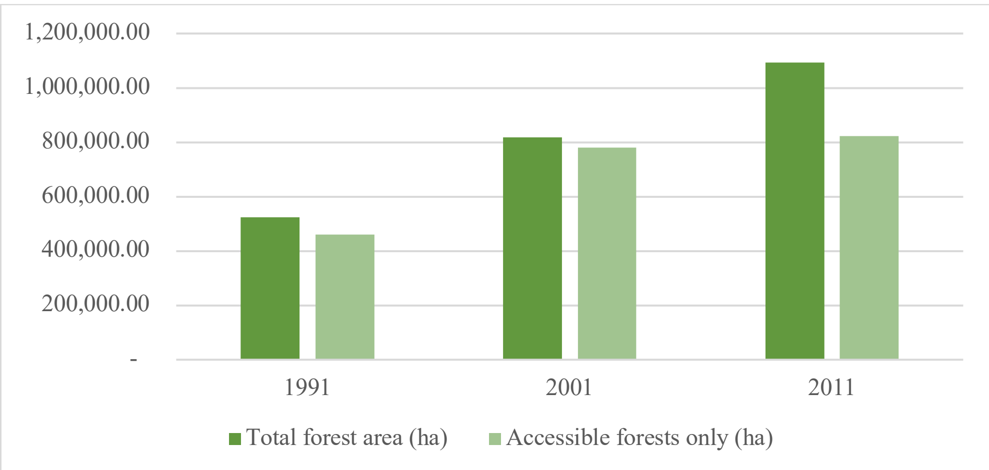


Fig. 4.1: Forest cover in Scotland in 1991, 2001 and 2011 (ha).

4.3.2 *People's access to forests in Scotland*

4.3.2.1 The whole of Scotland

Across the whole of Scotland, the population weighted mean distance to the nearest forest reduced from 2,287m in 1991 to 1,495m in 2001 then to 687m in 2011, which suggests that people's proximity to forests improved (Table 4.1). There were similar findings when only publicly accessible forests were considered. The mean distances were larger (1991 $\bar{x}$ = 2,392.00m; 2001 $\bar{x}$ = 1,546.81m; 2011 $\bar{x}$ = 1,373.84m) which was expected as there were fewer forests identified as accessible.

4.3.2.2 Differences within Scotland

The next stage was to examine differences in forest proximity by area-level deprivation and other environmental indicators. There was not a clear trend across deprivation quintiles. In 1991 and 2001, the least deprived (1991 $\bar{x}$ = 1,011.32m; 2001 $\bar{x}$ = 635.68m) and second least deprived areas (1991 $\bar{x}$ = 4,623.63m; 2001 $\bar{x}$ = 3,127.47m) had the best and worst access to forests respectively (Table 4.2). In 2011, this pattern shifted as the least deprived had the worst access (2011 $\bar{x}$ = 983.07m) and the second most deprived areas had the best (2011 $\bar{x}$ = 473.11m).

Areas in the Highlands and Islands (1991 $\bar{x}$ = 20,954.79m; 2001 $\bar{x}$ = 14,906.95m; 2011 $\bar{x}$ = 4,160.55m) and those in remote rural areas (1991 $\bar{x}$ = 13,453.70m; 2001 $\bar{x}$ = 9,963.57m; 2011 $\bar{x}$ = 9,620.55m) had the worst access to forests at each of the three time points. On the other hand, areas in South Scotland (1991 $\bar{x}$ = 737.22m) and Central Scotland (2001 $\bar{x}$ = 676.91m; 2011 $\bar{x}$ = 522.58m) experienced the best access over the study period, as did accessible small towns (1991 $\bar{x}$ = 809.09m; 2011 $\bar{x}$ = 516.52m) and accessible rural areas (2001 $\bar{x}$ = 587.10m). Similar trends were found when examining accessible forests only.

4.3.2.3 Excluding island postcodes

As described in the previous chapter, the analysis was repeated with island postcodes excluded. This was because many of the islands did not have forest cover and therefore generated exceptionally high values for distance to the nearest forest. When island postcodes were excluded from the analysis (approximately 2% of all postcodes), the mean distances to the nearest forests were reduced by approximately 30-60% (Table 4.1). The findings also suggested that the relationship between area-level deprivation and forest proximity was different on islands than on the mainland (Table 4.2). In the sample with island postcodes excluded there was a clear and consistent gradient in forest proximity across the quintiles with the most deprived areas having the worst access to forests at each of the three time points and the least deprived areas having the best access.

Relative inequality in forest access was measured by calculating the quintile ratio (Q5 – most deprived: Q1 – least deprived) at each time point. This showed that inequality in forest access between the most and least deprived areas had reduced over the study period, and in some cases indicate that a reverse in trend i.e. in 2011 the most deprived quintile has a lower mean distance to the nearest forest than the least deprived. When all forests were considered, the ratio reduced from 1.71 (1991), to 1.35 (2001) then to 0.57 (2011). However, when excluding the island communities, the reduction in the ratio between 2001 and 2011 was substantially smaller (1991=1.85, 2001=1.36, 2011=1.35). Furthermore, when this quintile ratio was calculated separately for urban and rural areas (as shown in Table 4.3, excluding island postcodes), the ratio slightly increased between 2001 and 2011 for urban areas (1991=1.74, 2001=1.32, 2011=1.35) but consistently reduced for rural areas across the three time points (1991=1.08, 2001=0.97, 2011=0.73). These results suggest that excluding island postcodes is more helpful in understanding the pattern of forest access improvements in Scotland, as they are identified as atypical of the Scottish population, with particularly large distances to the nearest forest. Any changes in forest proximity, particularly in Shetland, Orkney and the Outer Hebrides have a disproportionate effect on the data distribution.

Importantly, the results indicated that the reductions in forest proximity inequality between the most and least deprived areas in urban areas mainly took place between 1991 and 2001, and in rural areas between 2001 and 2011, and that inequality in proximity to all forests increased slightly in urban areas in the latter period.

Due to these findings and the demographic and socioeconomic differences between the island and mainland populations highlighted in Chapter 3, the subsequent analyses in this chapter and the rest of the thesis were conducted with island communities excluded, whilst differences between urban and rural areas continued to be investigated.

	All of Scotland			**Excluding island postcodes**		
	1991	**2001**	**2011**	**1991**	**2001**	**2011**
All forests						
n	118,099.00	129,472.00	136,822.00	115,373.00	126,401.00	133,589.00
mean	2,287.30	1,494.51	687.35	1,186.43	717.50	474.38
sd	13,998.78	10,552.29	2,920.57	918.53	602.95	415.62
minimum	0.00	0.00	0.00	0.00	0.00	0.00
maximum	270,981.20	222,311.80	88,616.00	28,414.70	10,209.30	8,520.40
Accessible forests only						
n	118,213.00	129,472.00	136,822.00	115,373.00	126,401.00	133,589.00
mean	2,392.00	1,546.81	1,373.84	1,260.66	733.58	595.50
sd	14,028.91	10,625.49	10,528.25	963.87	624.20	538.53
minimum	0.00	0.00	0.00	0.00	0.00	0.00
maximum	270,981.20	222,311.80	222,313.20	28,414.70	10,412.40	11,060.30

Table 4.1: Population weighted mean distances (m) to forests for all postcodes in Scotland, and when island postcodes are excluded, for 1991, 2001 and 2011 (sd=standard deviation).

	All of Scotland			Excluding island postcodes		
	1991	2001	2011	1991	2001	2011
Carstairs deprivation index (quintiles)						
All forests						
1 (least deprived)	1,011.32	635.68	983.07	922.63	632.98	413.77
2	4,623.63	3,127.47	607.66	988.08	693.66	496.20
3	2,841.29	1,979.15	806.09	1,097.60	675.74	438.96
4	1,208.42	864.77	473.11	1,210.56	724.80	463.30
5 (most deprived)	1,728.76	859.50	559.58	1,706.84	859.40	558.89
Ratio Q5:Q1	1.71	1.35	0.57	1.85	1.36	1.35
Accessible forests						
1 (least deprived)	1,068.42	653.61	2,805.64	979.21	650.57	544.72
2	4,722.38	3,240.99	838.79	1,066.37	711.67	613.46
3	2,947.32	2,067.07	1,815.33	1,174.60	697.73	535.27
4	1,317.60	896.67	688.17	1,305.36	737.89	598.38
5 (most deprived)	1,881.30	869.38	688.86	1,771.40	869.28	684.56
Ratio Q5:Q1	1.76	1.33	0.25	1.81	1.34	1.26
Urban rural classification (6-fold)						
All forests						
Large urban	1,614.68	796.35	505.11	1,614.68	796.35	505.11
Other urban	981.40	719.30	477.21	981.40	719.30	477.21
Accessible small town	758.15	641.11	424.08	758.15	641.11	424.08
Remote small town	9,920.09	6,587.61	2,120.56	1,187.27	732.19	547.46
Accessible rural	743.57	550.48	415.23	743.56	550.49	415.23
Remote rural	12,772.01	9,349.39	2,809.84	753.10	590.02	393.72
Accessible forests						
Large urban	1,661.86	801.77	619.84	1,661.86	801.77	619.84
Other urban	1,053.11	731.69	586.14	1,053.11	731.69	586.14
Accessible small town	809.09	660.48	516.52	809.09	660.48	516.52
Remote small town	9,962.11	6,621.53	6,023.42	1,235.64	770.55	693.84
Accessible rural	873.44	587.10	566.60	873.43	587.11	566.61
Remote rural	13,453.70	9,963.57	9,620.55	996.30	646.21	604.35

Table 4.2: Population weighted mean distances (m) to forests for all postcodes in Scotland, and when island postcodes are excluded, stratified by Carstairs deprivation quintile, urban rural classification (6-fold) and FCS Conservancy region.

	All of Scotland			Excluding island postcodes		
	1991	2001	2011	1991	2001	2011
FCS conservancy region						
All forests						
Central Scotland	1,246.25	666.41	426.70	1,247.30	667.28	427.07
Grampian	1,091.11	1,016.85	610.53	1,091.11	1,016.85	610.53
Highlands and Islands	20,954.79	14,906.95	4,160.55	1,108.55	813.44	522.54
Perth & Argyll	1,198.74	731.53	529.91	1,156.64	703.34	505.65
South Scotland	972.55	690.89	556.77	972.55	690.89	556.77
Accessible forests						
Central Scotland	1,310.91	676.91	522.58	1,311.80	677.63	522.97
Grampian	1,154.34	1,033.36	806.97	1,154.34	1,033.36	806.97
Highlands and Islands	21,652.82	15,597.57	14,161.95	1,318.58	856.48	712.29
Perth & Argyll	1,288.06	748.03	643.40	1,237.12	718.10	616.63
South Scotland	1,056.23	733.45	737.22	1,056.23	733.45	737.22

Table 4.2: (continued).

	Urban			Rural		
Carstairs deprivation index (quintiles)	**1991**	**2001**	**2011**	**1991**	**2001**	**2011**
All forests						
1 (least deprived)	1,000.47	663.46	417.41	683.58	546.24	405.99
2	1,114.38	773.54	527.64	671.10	508.08	415.95
3	1,147.90	676.38	437.33	829.95	672.08	449.16
4	1,229.40	733.10	472.90	1,014.15	627.29	361.09
5 (most deprived)	1,743.55	873.69	564.67	737.72	532.04	294.36
Ratio Q5:Q1	1.74	1.32	1.35	1.08	0.97	0.73
Accessible forests only						
1 (least deprived)	1,035.95	674.58	532.12	804.92	582.25	571.64
2	1,171.61	782.55	628.24	802.25	546.98	575.73
3	1,191.12	691.77	512.56	1,086.72	731.69	676.99
4	1,314.57	743.73	608.39	1,209.33	669.23	491.78
5 (most deprived)	1,801.15	881.83	690.59	985.90	581.73	408.60
Ratio Q5:Q1	1.74	1.31	1.30	1.22	1.00	0.71

Table 4.3: Population weighted mean distances (m) to the nearest forest for all postcodes in mainland Scotland, stratified by Carstairs deprivation index (quintiles) and urban rural classification (6-fold).

4.3.3 Changes in access to forests from 1991 to 2001; and from 2001 to 2011

Changes in proximity to forests over time during the study period were then explored for 1991, 2001 and 2011 for the population of mainland Scotland only, using mixed-effects linear regression models, adjusted by postcode population size. Geographical differences within Scotland were also examined by area-level deprivation, rurality and region, as were differences between proximity to all forests and those identified as publicly accessible. The model coefficients indicated that forest proximity improved significantly for mainland Scotland between the three time points (Table 4.4). There was a greater improvement in distance to the nearest forest (m) over time between 1991 and 2001 (all forests β: -465.67, CI: -469.65, -461.69) than between 2001 and 2011 (all forests β: -254.14, CI: -258.12, -250.16). Results for accessible forests were similar. When differences between different areas of Scotland were examined (Table 4.5), the greatest improvements were in distance to the accessible forests and took place between 1991 and 2001 in the most deprived areas (accessible forests β:-1134.39, CI:-1145.37,-1123.41), in large urban areas (accessible forests β: -965.40, CI: -971.76, -959.03) and in Central Scotland (accessible forests β:-765.99, CI:-771.25,-760.74). The results of the Wald tests indicated that the changes in forest proximity varied significantly between deprived and affluent neighbourhoods, urban and rural areas, and FCS regions ($p<0.0001$).

	All forests β (95% CI)	**Accessible forests β (95% CI)**
Unadjusted models		
1991-2001	-465.67 (-470.11, -462.16)	-525.82 (-529.54, -522.10)
2001-2011	-253.78 (-257.76, -249.80)	-123.85 (-127.57, -120.13)
Adjusted models		
1991-2001	-465.67 (-469.65, -461.69)	-525.41 (-529.14, -521.69)
Population size	-0.73 (-0.80, -0.66)	-0.64 (-0.72, -0.57)
2001-2011	-254.14 (-258.12, -250.16)	-124.16 (-127.89, -120.44)
Population size	-0.73 (-0.80, -0.66)	-0.64 (-0.72, -0.57)

Table 4.4: Coefficients indicating changes (1991-2001; 2001-2011) in distance to the nearest forests for all postcodes in mainland Scotland (m).

	Distance to the nearest forest		Distance to the nearest accessible forest	
	1991 to 2001	2001 to 2011	1991 to 2001	2001 to 2011
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Carstairs deprivation index (quintiles)				
1(least deprived)	-224.73 (-230.70, -218.59)	-226.34 (-232.34, -220.33)	-267.00 (-273.05, -260.95)	-95.96 (-102.03, -89.89)
2	-302.87 (-310.38, -295.36)	-202.51 (-209.99, -195.02)	-372.85 (-381.83, -363.87)	-64.77 (-73.67, -55.87)
3	-337.96 (-348.55, -327.38)	-285.30 (-295.45, -275.14)	-401.14 (-411.10, -391.18)	-182.84 (-192.34, -173.35)
4	-486.49 (-495.08, -477.90)	-288.48 (-296.88, -280.07)	-562.97 (-572.58, -553.35)	-147.79 (-157.19, -138.38)
5(most deprived)	-1085.37(-1096.05,-1074.69)	-284.85 (-295.21, -274.48)	-1134.39(-1145.37,-1123.41)	-154.70 (-165.36, -144.04)
Urban rural classification (6-fold)				
Large urban	-931.36 (-937.79, -924.93)	-321.42 (-327.85, -315.00)	-965.40 (-971.76, -959.03)	-172.56 (-178.93, -166.19)
Other urban	254.93 (-259.77, -250.10)	-241.14 (-245.97, -236.30)	-309.70 (-315.04, -304.36)	-139.89 (-145.23, -134.55)
Accessible small town	-117.34 (-124.98, -109.70)	-228.43 (-236.07, -220.80)	-149.69 (-158.46, -140.93)	-168.93 (-177.69, -160.17)
Remote small town	-414.64 (-436.03, -393.28)	-155.81 (-177.19, -134.44)	-416.06 (-437.96, -394.15)	-81.32 (-103.22, -59.41)
Accessible rural	-122.41 (-128.13, -116.70)	-164.89 (-170.60, -159.17)	-212.81 (-219.59, -206.02)	-26.02 (-32.80, -19.24)
Remote rural	-27.27 (-50.96, -3.46)	-236.78 (-260.53, -213.03)	-202.40 (-218.27, -186.53)	-39.65 (-55.52, -23.78)
FCS region				
Central Scotland	-718.82 (-723.95, -713.68)	-226.53 (-231.67, -221.39)	-765.99 (-771.25, -760.74)	-134.51 (-139.77, -129.26)
Grampian	-20.37 (-27.11, -13.63)	-417.65 (-424.39, -410.91)	-65.23 (-71.66, -58.81)	-206.43 (-212.86, -200.01)
Highlands & Islands	-176.69 (-226.13, -127.26)	-353.11 (-402.54, -303.67)	-433.39 (-465.32, -401.46)	-86.43 (-118.35, -54.50)
Perth & Argyll	-420.10 (-427.62, -412.58)	-181.90 (-189.42, -174.38)	-486.47 (-494.66, -478.27)	-79.68 (-87.87, -71.48)
South Scotland	-268.61 (-274.86, -262.35)	-122.80 (-129.05, -116.55)	-329.58 (-337.55, -321.60)	13.76 (5.79, 21.74)

Table 4.5: Coefficients indicating changes (1991-2001; 2001-2011) in forest proximity for all postcodes in mainland Scotland (m), stratified by Carstairs deprivation quintile, urban-rural classification (6-fold) and FCS conservancy region.

4.4 Summary

This chapter has described the analysis techniques employed in an investigation of how forest cover and proximity to forests for the population of Scotland have changed over time for the last three census years; and for identifying evidence of whether changes in forest proximity varied between different types of area and locations, indicating potential reinforcement or reduction of patterns of environmental injustice. Findings showed that forest cover increased and people's proximity to forests improved over the time periods studied, with the greatest improvements taking place between 1991 and 2001. When islands were excluded from the sample, the most deprived areas of Scotland continued to have the worst proximity to forests at each of the three time points, despite experiencing large decreases in distance to the nearest forest, which suggests environment injustices may remain. Changes in forest proximity also varied by geographical region and between urban and rural areas, with more populated areas experiencing greater improvements. Examining the differences in forest proximity between the most and least deprived areas of Scotland showed that inequalities had reduced over the study period, but less so when islands were excluded from the sample, and that the largest reductions in inequalities took place in urban areas between 1991 and 2001 and in rural areas between 2001 and 2011. These issues will be discussed further in Chapter 8, taking into account how Scotland's forest landscape has changed over time as a result of transitions in forestry policies and practices; and how this has shaped socially uneven patterns of forest proximity through processes that continue to reflect environmental injustice.

As highlighted in Chapter 2, the health outcomes of environmental injustices are rarely investigated from a longitudinal perspective and no studies to date have specifically focused on access to forests. The next chapter examines the relationship between different trajectories of forest proximity and various health outcomes over time using a sample of individuals in the Scottish Longitudinal Study (SLS).

5 The relationship between forest access trajectories and health

5.1 Introduction

Using area-level data, the previous chapter showed that although forest access had improved across the three study time points, changes were uneven across areas of Scotland, providing evidence relating to environmental injustice. This next section of analyses investigated the potential outcomes of uneven forest access for health. Using individual-level data from the SLS and linked administrative health records, this chapter explored the relationship between forest access and health cross-sectionally and longitudinally. In particular, it investigated whether there were distinct trajectories of forest access among the population and whether people with better forest access trajectories had better general and mental health at the end of the study period. Potential evidence relating to environmental injustice and implications for health inequalities were also investigated by testing whether individual-level characteristics including age, sex and socioeconomic status predicted particular forest access trajectories. The specific aim and research questions were:

To examine the relationship between different patterns of forest access over a 20-year period (1991-2011) and subsequent health outcomes.

- Is access to forests in 1991, 2001 and 2011 associated with general and mental health outcomes during the period 2011-2016?
- To what extent do sociodemographic characteristics of individuals predict individuals' forest access trajectories?
- Are different trajectories of forest access between 1991 and 2011 predictive of general and mental health outcomes during 2011-2016?

The chapter consists of two main sections. Firstly, the analytical approach and statistical techniques applied in order to investigate the above questions are described. Then, the results of the analysis are presented.

5.2 **Analysis plan**

5.2.1 The relationship between forest access at different time points and health in 2011-2016

The relationship between each of the two forest proximity variables: (1) distance to the nearest forest and (2) distance to the nearest accessible forests in 1991, 2001 and 2011, and health outcomes during 2011-2016 were assessed using chi square tests. The specific health outcomes explored were:

- Had bad general health 2011 (yes/no)
- Had a long-term illness 2011 (yes/no)
- Had a mental health condition 2011 (yes/no)
- Prescribed antidepressants 2011-2016 (yes/no)
- Prescribed anxiolytics 2011-2016 (yes/no)
- Prescribed antidepressants or anxiolytics 2011-2016 (yes/no)
- Attended mental health outpatient appointment 2011-2016 (yes/no)
- Admitted as a mental health inpatient 2011-2016 (yes/no)

Significant relationships between forest access and health in 2011 or 2011-2016 were then explored further using binary logistic regression models, adjusted by demographic, socioeconomic and environmental factors. Justification for each of the covariates chosen is provided in Chapter 3. After investigating the association of individual covariates with the health outcomes and forest proximity measures, models were constructed in four steps. Firstly, the health outcome and forest proximity measure were modelled together. Then demographic factors (sex, age group, ethnicity and children in the household) were added. In step 3, models were adjusted for individual- and household-level socioeconomic variables (highest-level education and housing tenure). Finally, the models were adjusted for environmental characteristics (urban-rural classification (6-fold) and distance to the coastline (km)). Adding variables in these steps allowed the effect of each group of variables on the relationship between forest access and health to be assessed.

5.2.1.1 Sensitivity analysis

As highlighted in Chapter 3, administrative records for prescriptions do not contain a diagnosis or the reason why the medication has been prescribed. This is a potential problem as certain types of antidepressants, mainly amitriptyline, are used to treat conditions other than depression, e.g. migraines and chronic pain at doses less than 30mg per day. To address this concern, the above steps were also conducted with those on low doses (<30mg per day) of amitriptyline classified as not receiving prescriptions for antidepressants, following the prescribing recommendations stated in the British National Formulary (BNF) (National Institute for Health and Care Excellence 2018).

5.2.2 Trajectories of forest access and health outcomes

5.2.2.1 Building forest access trajectory models

In order to identify different patterns of forest access over time across the sample, trajectories of people's forest proximity were investigated taking all forests into consideration then for accessible forests only. Latent Class Growth Modelling (LCGM) was conducted using the 'traj' command in Stata (Jones & Nagin 2013). This analysis allowed SLS members to be classified into groups according to the changes in forest proximity over the study period, with people who had followed similar trajectories of change in forest proximity being allocated to the same group. The 'traj' command also generated a categorical variable which specified which trajectory group each SLS member had been allocated to. In order to determine the optimum number of trajectory groups and model function, the approach by Kwon et al. (2015) was used. Firstly, five separate models with different numbers of groups were specified (Model 1 specified two trajectory groups, Model 2 specified three trajectory groups etc.) and conducted with a quadratic function. The model with the lowest Bayesian Information Criteria (BIC) was selected as the final model. BIC is used to compare goodness-of-fit between non-nested models, whereby the log-likelihood is decreased by a certain value, depending on the number of predictors in a model and sample size. The model with the smallest BIC value can then be identified as the best-fitting (Singer & Willett 2003). To select the optimal function for each group (quadratic, cubic, linear or constant), the function specified was decreased from quadratic to cubic to linear to constant, until an odds ratio for a parameter in each variable in the model was significant ($p<0.05$).

5.2.2.2 Demographic and socioeconomic determinants of forest access trajectories

Binary logistic regression was used to assess whether demographic and socioeconomic characteristics of individuals were significantly associated with the likelihood of being allocated to a particular trajectory group. The indicators tested were sex, age, ethnicity, children in the household, highest-level education and housing tenure at the first time point. Dummy variables, specifying which trajectory group the SLS members had been allocated to, were created. The association between each of the sociodemographic indicators and the trajectory grouping variables was first tested using chi square tests. Significant associations were investigated further using binary logistic regression models, with the trajectory group dummy variables as the outcomes and demographic and socioeconomic indicators as the exposure measures. The variables were added to the model together in one step. Following the approach by Séguin et al. (2012), those which were not significant ($p>0.05$) were dropped from the model and the value of the Wald statistic was used to identify the most important predictors, whereby those with higher Wald values had more predictive power (Kirkwood & Sterne 2010).

5.2.2.3 Testing relationships between forest access trajectories and health outcomes

In order to assess whether different forest access trajectories led to variations in health outcomes in 2011, binary logistic regression models were conducted with the forest access trajectory grouping variables as the exposures. Models were adjusted by sex, age group, ethnicity, children in the household, highest-level educational qualification, housing tenure, urban-rural classification and distance to the coastline. Covariates were added to the model in one step, as earlier exploratory analysis had already established the influence of individual confounders on the relationship between forests and health outcomes.

5.3 **Results**

5.3.1 About the sample

The final study population contained 97,658 people living in Scotland in 1991, 2001 and 2011. People living on the Scottish islands (2,176), in communal residences (2,286) and those with missing data (11,051) were excluded from the original sample for the reasons provided in Chapter 3. Earlier analysis on missing data, also described in Chapter 3, did not demonstrate nonresponse bias in the sample. Descriptive statistics indicated that people's forest access improved between the three time points (Table 5.1). The proportion of individuals living within 500m of forests (which has been considered walking distance) increased (1991=24.91%, 2001=45.32%, 2011=64.71%). The same trend was found when examining accessible forests only.

The amount of people with a long-term illness increased markedly throughout the study period (1991=7.04%, 2001=19.38%, 2011=28.56%), probably due to an ageing effect. In 1991, the largest age group was those aged 30-44 (39.19%) and approximately 29% were adults under thirty years old. A smaller proportion were aged 45 and over (45-54=18.73%, 55+ =12.89%). Again, this ageing effect was due to the sample only including those present in all three censuses. This was necessary to enable changes in forest access and changes in health to be examined. Approximately 4% of the sample reported a mental health condition in the 2011 census, whereas 33.07% and 14.67% were prescribed antidepressants and anxiolytics respectively between 2011 and 2016. The prescribing rates for antidepressants and anxiolytics in 2011 only were 3.85% and 1.20% respectively. Excluding cases where amitriptyline was given at doses less than 30mg per day, reduced the proportion of people receiving antidepressants in 2011-2016 by approximately 5%. Less than 1% were mental health inpatients and 5.20% attended mental health outpatient appointments during this period. The SLS members' sex and ethnicity was as reported in the 1991 census. Around 99% of the sample were white, 54.04% were female and 45.95% were male, which are comparable proportions to that of the Scottish population in 1991 (National Records of Scotland 2018b).

As described in Chapter 3, probabilities of visiting forests at least weekly, monthly and annually were estimated from the Scottish People and Nature Survey 2013-2014 (SPANS) and linked to the SLS members at each of the three time points, based on reported values for ethnicity, age and housing tenure (Table 5.2). Across the three time points, the average probability of visiting forests at least weekly remained at 22-24%. For visiting at least monthly and at least annually the average probabilities were greater and decreased over the study period (mean probability of visiting at least monthly: 1991=45.25%, 2001=44.55%, 2011=41.25%; mean probability of visiting at least annually: 1991=81.66%, 2001=80.23%, 2011=75.57%).

	Census data						Administrative health data			
Variables / time points	**1991**		**2001**		**2011**		**2011-2016**		**Before 2011***	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Distance to the nearest forest (m)										
0-<150	5,408	5.54	12,827	13.13	20,611	21.11				
150-<300	7,363	7.54	13,833	14.16	20,656	21.15				
300-<500	11,556	11.83	17,604	18.03	21,923	22.45				
500-<750	14,347	14.69	17,494	17.91	16,761	17.16				
750-<1500	32,532	33.31	26,179	26.81	14,989	15.35				
>=1500	26,452	27.09	9,721	9.95	2,718	2.78				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
Distance to the nearest accessible forest (m)										
0-<150	5,141	5.26	12,643	12.95	17,010	17.42				
150-<300	6,754	6.92	13,505	13.83	17,198	17.61				
300-<500	10,539	10.79	17,225	17.64	19,451	19.92				
500-<750	13,161	13.48	17,275	17.69	17,450	17.87				
750-<1500	32,188	32.96	26,734	27.38	20,675	21.17				
>=1500	29,875	30.59	10,276	10.52	5,874	6.01				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
Long term limiting illness										
No	90,784	92.96	78,727	80.62	69,770	71.44				
Yes	6,874	7.04	18,931	19.38	27,888	28.56				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
General health										
Good					71,685	73.40				
Bad					25,973	26.60				
Total					97,658	100.00				
Mental health condition										
No					93,388	95.63				
Yes					4,270	4.37				
Total					97,658	100.00				
Prescribed antidepressants										
No							65,362	66.93	79,423	81.33
Yes							32,296	33.07	18,235	18.67
Total							97,658	100.00	97,658	100.00
Prescribed antidepressants (amitriptyline <30mg reclassified)										
No							70,351	72.04	82,340	84.31
Yes							27,307	27.96	15,318	15.69
Total							97,658	100.00	97,658	100.00

Table 5.1: The SLS sample, Source: Scottish Longitudinal Study.
*For prescribing outcomes, this variable was for the time period 2009-2010. For inpatient and outpatient outcomes, this variable was for the time period 1997-2010. These are used as control measures in Chapter 6 which explores associations between forests and mental health using life course models.

	Census data						Administrative health data			
Variables / time points	**1991**		**2001**		**2011**		**2011-2016**		**Before 2011***	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Prescribed anxiolytics										
No							83,336	85.33	91,449	93.64
Yes							14,322	14.67	6,209	6.36
Total							97,658	100.00	97,658	100.00
Admitted as mental health inpatient										
No							96,796	99.12	95,760	98.06
Yes							862	0.88	1,898	1.94
Total							97,658	100.00	97,658	100.00
Attended mental health outpatient clinic										
No							92,582	94.8	91,522	93.72
Yes							5,076	5.20	6,136	6.28
Total							97,658	100.00	97,658	100.00
Cohort / Age in 1991										
1/ 18-29	28,509	29.19	28,509	29.19	28,509	29.19				
2/ 30-44	38,274	39.19	38,274	39.19	38,274	39.19				
3/ 45-54	18,291	18.73	18,291	18.73	18,291	18.73				
4/ 55+	12,584	12.89	12,584	12.89	12,584	12.89				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
Sex										
Female	52,786	54.05	52,786	54.05	52,786	54.05				
Male	44,872	45.95	44,872	45.95	44,872	45.95				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
Ethnicity										
Not white	634	0.65	634	0.65	634	0.65				
White	97,024	99.35	97,024	99.35	97,024	99.35				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
Children in household										
No	54,710	56.02	63,082	64.59	76,433	78.27				
Yes	42,948	43.98	34,576	35.41	21,225	21.73				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
Highest-level educational qualification										
None	80,623	82.56	36,840	37.72	35,517	36.37				
Non-degree	9,673	9.90	40,814	41.79	38,873	39.81				
Degree	7,362	7.54	20,004	20.48	23,268	23.83				
Total	97,658	100.00	97,658	100.00	97,658	100.00				

Table 5.1: Continued

	Census data						Administrative health data			
Variables / time points	**1991**		**2001**		**2011**		**2011-2016**		**Before 2011***	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Housing tenure										
Owner	62,647	64.15	74,669	76.46	76,261	78.09				
Social rent	29,738	30.45	18,503	18.95	16,869	17.27				
Private rent	5,273	5.40	4,486	4.59	4,528	4.64				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
Carstairs deprivation index										
(1) Least deprived	22,354	22.89	23,070	23.62	22,502	23.04				
2	21,268	21.78	21,240	21.75	21,558	22.07				
3	19,866	20.34	19,571	20.04	19,899	20.38				
4	18,612	19.06	18,668	19.12	18,669	19.12				
(5) Most deprived	15,558	15.93	15,109	15.47	15,030	15.39				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
Urban rural classification										
Large urban areas	37,254	38.15	35,376	36.22	29,510	30.22				
Other urban areas	30,530	31.26	30,664	31.40	37,025	37.91				
Accessible small towns	10,565	10.82	11,030	11.29	10,222	10.47				
Remote small towns	2,302	2.36	2,306	2.36	3,262	3.34				
Accessible rural areas	13,075	13.39	14,070	14.41	12,832	13.14				
Remote rural areas	3,932	4.03	4,212	4.31	4,807	4.92				
Total	97,658	100.00	97,658	100.00	97,658	100.00				
Distance to the coastline (km)										
=<1km	9,985	10.22	10,347	10.60	10,615	10.87				
1< & =<5 km	22,733	23.28	21,860	22.38	21,359	21.87				
5< & =<20km	33,419	34.22	34,382	35.21	34,746	35.58				
>20 km	31,521	32.28	31,069	31.81	30,938	31.68				
Total	97,658	100.00	97,658	100.00	97,658	100.00				

Table 5.1: continued.

Synthetic estimates of forest use	1991	2001	2011
Probability of visiting forests at least weekly			
n	97,658	97,658	97,658
mean	23.43	23.73	22.45
standard deviation	2.85	3.20	4.00
minimum	10.46	10.44	7.66
maximum	27.58	27.58	27.58
Probability of visiting forests at least monthly			
n	97,658	97,658	97,658
mean	45.24	44.55	41.25
standard deviation	4.67	5.83	7.56
minimum	15.62	12.83	9.86
maximum	49.80	49.80	49.80
Probability of visiting forests at least annually			
n	97,658	97,658	97,658
mean	81.66	80.23	75.57
standard deviation	5.52	7.69	10.07
minimum	42.60	37.64	29.57
maximum	86.59	86.59	86.59

Table 5.2: Descriptive statistics for SLS members' forest use based on linked synthetic estimates derived from SPANS. Source: Scottish Longitudinal Study.

5.3.2 Cross-sectional relationships between forests and health

5.3.2.1 Bivariate analysis

Firstly, chi square tests were used to assess relationships between forest access and health in 2011. Associations between forest proximity at earlier time points and health in 2011 was also tested in order to assess whether there was a potential link through time.

Results showed significant relationships ($p<0.001$) between forest proximity at each time point (all forests and accessible forests) and the census health outcomes in 2011 (Table 5.3). The proportion of people with a long-term illness or bad general health increased as distance to the nearest forest in 2001 and 2011 increased, except for the furthest distance band (>=1500m from the nearest forest). The prevalence of mental health conditions generally increased as forest distance increased but this was not continuous from the nearest distance band to the furthest. Clearer trends were found when the 1991 forest proximity variables were tested against the same outcomes, as the amount of people with a long-term illness or bad general health continued to increase as forest distance increased. As shown in Table 5.4, forest proximity at each time point was associated with the prescribing of antidepressants in

2011-2016 ($p<0.001$). There were stronger relationships found between this outcome and earlier forest proximity than in 2011. Reclassifying those with amitriptyline at low doses as not being prescribed antidepressants, made very little difference to the relationship and no difference to the level of significance ($p<0.001$). Therefore, it was decided to continue the analysis, with low-dose amitriptyline patients included in the ‘yes’ category.

Mostly significant associations were found for attending a mental health outpatient appointment. These included the distance to all forests and accessible forests in 2011 (all forests $p<0.001$, accessible forests $p<0.01$) and 2001 (all forests $p<0.01$, accessible forests $p<0.05$). In 1991, the relationship was only significant when all forests were considered ($p<0.05$). No significant relationships were found for the prescribing of anxiolytics or being admitted as a mental health inpatient ($p>0.05$).

	Has a long-term illness 2011			Has bad general health 2011			Has a mental health condition 2011		
	No	**Yes**	**$\mathcal{X}^2$ significance level**	**No**	**Yes**	**$\mathcal{X}^2$ significance level**	**No**	**Yes**	**$\mathcal{X}^2$ significance level**
Distance to the nearest forest (m) 2011 (%)			p<0.001			p<0.001			p<0.001
0-<150	74.43	25.57		76.23	23.77		96.21	3.79	
150-<300	71.47	28.53		73.44	26.56		95.65	4.35	
300-<500	70.58	29.42		72.30	27.70		95.42	4.58	
500-<750	69.96	30.04		72.29	27.71		95.29	4.71	
750-<1500	70.02	29.98		72.13	27.87		95.35	4.65	
>=1500	72.52	27.48		74.50	25.50		96.43	3.57	
Distance to the nearest accessible forest (m) 2011 (%)			p<0.001			p<0.001			p<0.001
0-<150	74.64	25.36		76.51	23.49		96.24	3.76	
150-<300	71.72	28.28		73.83	26.17		95.64	4.36	
300-<500	70.51	29.49		72.36	27.64		95.55	4.45	
500-<750	70.48	29.52		72.37	27.63		95.21	4.79	
750-<1500	70.00	30.00		72.09	27.91		95.45	4.55	
>=1500	72.39	27.61		74.34	25.66		95.90	4.10	
Distance to the nearest forest (m) 2001 (%)			p<0.001			p<0.001			p<0.001
0-<150	83.49	16.51		77.36	22.64		96.50	3.50	
150-<300	81.12	18.88		74.45	25.55		95.61	4.39	
300-<500	80.56	19.44		73.20	26.80		95.60	4.40	
500-<750	80.06	19.94		72.53	27.47		95.39	4.61	
750-<1500	79.54	20.46		72.08	27.92		95.50	4.50	
>=1500	80.09	19.91		72.18	27.82		95.31	4.69	
Distance to the nearest accessible forest (m) 2001 (%)			p<0.001			p<0.001			p<0.001
0-<150	83.56	16.44		77.36	22.64		96.50	3.50	
150-<300	81.20	18.80		74.45	25.55		95.62	4.38	
300-<500	80.39	19.61		73.13	26.87		95.56	4.44	
500-<750	80.09	19.91		72.56	27.44		95.40	4.60	
750-<1500	79.60	20.40		72.22	27.78		95.53	4.47	
>=1500	80.12	19.88		72.12	27.88		95.34	4.66	
Distance to the nearest forest (m) 1991 (%)			p<0.001			p<0.001			p<0.001
0-<150	94.51	5.49		77.02	22.98		96.01	3.99	
150-<300	94.06	5.94		76.6	23.40		96.39	3.61	
300-<500	93.86	6.14		75.2	24.80		95.91	4.09	
500-<750	93.11	6.89		73.4	26.60		96.01	3.99	

Table 5.3: Chi square associations between forest access and census health outcomes in 2011. Source: Scottish Longitudinal Study.

750-<1500	92.70	7.30		72.7	27.30		95.60	4.40	
>=1500	92.19	7.81		71.86	28.14		95.05	4.95	
Distance to the nearest accessible forest (m) 1991 (%)			p<0.001			p<0.001			p<0.001
0-<150	94.42	5.58		77.01	22.99		95.97	4.03	
150-<300	94.06	5.94		76.65	23.35		96.37	3.63	
300-<500	94.10	5.90		75.28	24.72		95.85	4.15	
500-<750	93.21	6.79		73.6	26.40		96.11	3.89	
750-<1500	92.64	7.36		72.73	27.27		95.55	4.45	
>=1500	92.29	7.71		72.03	27.97		95.19	4.81	

Table 5.3: continued.

	Prescribed antidepressants 2011-2016			**Prescribed anxiolytics 2011-2016**			**Admitted as mental health outpatient 2011-2016**			**Admitted as mental health inpatient 2011-2016**		
	No	**Yes**	**$\mathcal{X}^2$ significance level**	**No**	**Yes**	**$\mathcal{X}^2$ significance level**	**No**	**Yes**	**$\mathcal{X}^2$ significance level**	**No**	**Yes**	**$\mathcal{X}^2$ significance level**
Distance to the nearest forest (m) 2011 (%)			p<0.001			Ns			p<0.001			ns
0-<150	68.38	31.62		85.39	14.61		95.29	4.71		99.16	0.84	
150-<300	66.95	33.05		85.20	14.80		94.99	5.01		99.18	0.82	
300-<500	66.42	33.58		85.45	14.55		94.67	5.33		99.07	0.93	
500-<750	66.30	33.70		85.11	14.89		94.67	5.33		99.16	0.84	
750-<1500	65.92	34.08		85.29	14.71		94.34	5.66		99.01	0.99	
>=1500	69.28	30.72		86.64	13.36		94.11	5.89		98.97	1.03	
Distance to the nearest accessible forest(m) 2011 (%)			p<0.001			Ns			p<0.01			ns
0-<150	68.61	31.39		85.44	14.56		95.33	4.67		99.15	0.85	
150-<300	67.21	32.79		85.46	14.54		94.95	5.05		99.22	0.78	
300-<500	66.40	33.60		85.03	14.97		94.67	5.33		99.13	0.87	
500-<750	66.25	33.75		85.10	14.90		94.85	5.15		99.12	0.88	
750-<1500	65.99	34.01		85.31	14.69		94.43	5.57		99.01	0.99	
>=1500	68.32	31.68		86.47	13.53		94.42	5.58		99.05	0.95	
Distance to the nearest forest(m) 2001 (%)			p<0.001			ns			p<0.01			ns
0-<150	69.63	30.37		85.78	14.22		95.05	4.95		99.17	0.83	
150-<300	67.38	32.62		85.47	14.53		95.12	4.88		99.14	0.86	
300-<500	66.62	33.38		85.41	14.59		95.06	4.94		99.16	0.84	

Table 5.4: Chi square associations between forest access and administrative health outcomes in 2011-2016 (ns=not significant). Source: Scottish Longitudinal Study.

	Prescribed antidepressants 2011-2016			Prescribed anxiolytics 2011-2016			Admitted as mental health outpatient 2011-2016			Admitted as mental health inpatient 2011-2016		
	No	**Yes**	**$\mathcal{X}^2$ significance level**	**No**	**Yes**	**$\mathcal{X}^2$ significance level**	**No**	**Yes**	**$\mathcal{X}^2$ significance level**	**No**	**Yes**	**$\mathcal{X}^2$ significance level**
500-<750	66.39	33.61		85.32	14.68		94.62	5.38		99.10	0.90	
750-<1500	66.13	33.87		85.08	14.92		94.69	5.31		99.17	0.83	
>=1500	66.41	33.59		85.12	14.88		94.20	5.80		98.84	1.16	
Distance to the nearest accessible forest(m) 2001 (%)			p<0.001			ns			p<0.05			ns
0-<150	69.70	30.30		85.76	14.24		95.04	4.96		99.17	0.83	
150-<300	67.38	32.62		85.47	14.53		95.10	4.90		99.12	0.88	
300-<500	66.51	33.49		85.30	14.70		95.08	4.92		99.14	0.86	
500-<750	66.20	33.80		85.35	14.65		94.56	5.44		99.14	0.86	
750-<1500	66.31	33.69		85.15	14.85		94.68	5.32		99.16	0.84	
>=1500	66.49	33.51		85.14	14.86		94.37	5.63		98.85	1.15	
Distance to the nearest forest(m) 1991 (%)			p<0.001			ns			p<0.05			ns
0-<150	68.69	31.31		85.48	14.52		95.14	4.86		99.15	0.85	
150-<300	69.10	30.90		85.43	14.57		95.30	4.70		99.09	0.91	
300-<500	67.78	32.22		85.69	14.31		95.12	4.88		99.23	0.77	
500-<750	67.59	32.41		85.28	14.72		95.01	4.99		99.09	0.91	
750-<1500	66.46	33.54		85.45	14.55		94.57	5.43		99.11	0.89	
>=1500	65.81	34.19		85.01	14.99		94.62	5.38		99.09	0.91	
Distance to the nearest accessible forest(m) 1991 (%)			p<0.001			ns			ns			ns
0-<150	68.66	31.34		85.55	14.45		95.08	4.92		99.12	0.88	
150-<300	69.26	30.74		85.52	14.48		95.25	4.75		99.08	0.92	
300-<500	67.71	32.29		85.75	14.25		95.05	4.95		99.18	0.82	
500-<750	67.62	32.38		85.47	14.53		95.02	4.98		99.13	0.87	
750-<1500	66.60	33.40		85.28	14.72		94.58	5.42		99.13	0.87	
>=1500	65.88	34.12		85.10	14.90		94.71	5.29		99.08	0.92	

Table 5.4: continued.

5.3.2.2 Multivariate analysis – Forest access and health in 2011

As detailed in section 5.2.1, significant associations between forest access and health outcomes in 2011-2016 were further explored using binary logistic regression models, controlled for demographic, socioeconomic and environmental indicators at the same time point. Firstly, the three census outcomes (general health, long-term illness and mental health) were each modelled with distance to the nearest forest in 2011. Covariates were added in three steps, as described in section 5.2.1.

The final models are shown in Table 5.5. Compared to those living <150m from the nearest forest, people with greater distances to the nearest forest had significantly increased odds of having worse health outcomes. Those who lived 500-750m from the nearest forest were 14% more likely to have a long-term illness (500-<750m OR=1.14, 95% CI=1.08-1.20) and 10% more likely to have worse general health (500-<750m OR=1.10, 95% CI=1.04-1.16). The effects varied in size from 5 to 14% and did not increase as distance to the nearest forest reduced. The relationship did not hold for those living >=1500m from the nearest forest and no significant results were found when mental health was modelled.

When only accessible forests were considered (Table 5.6), significantly increased odds of having a long-term illness compared to those living nearest to forests were found for all of the forest proximity categories. Those living 500-<750m from the nearest accessible forest were 12% more likely to have a long-term illness than those living closest 0-150m (OR: 1.12, 95% CI: 1.06-1.18). People living 300-<500m or further from the nearest accessible forest were also significantly more likely to have worse general health. However, there was no significant difference between those living closest to forests and those 150-<300m from the nearest accessible forest. Only one distance band was found to be associated with having a mental health condition (500-<750m OR: 1.12, 95% CI: 1.00-1.24).

	Has a long-term illness 2011		Has bad general health 2011		Has a mental health condition 2011	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Distance to the nearest forest (m) 2011 (reference: 0-<150m)						
150-<300	**1.07**	1.02-1.12	**1.05**	1.00-1.11	1.04	0.94-1.15
300-<500	**1.10**	1.05-1.15	**1.10**	1.05-1.15	1.08	0.98-1.19
500-<750	**1.14**	1.08-1.20	**1.10**	1.04-1.16	1.08	0.98-1.20
750-<1500	**1.10**	1.04-1.16	**1.08**	1.02-1.14	1.05	0.94-1.17
>=1500	1.05	0.95-1.16	1.07	0.96-1.18	0.91	0.73-1.15
Age group 2011 (reference: 38-49)						
50-64	**1.77**	1.69-1.86	**1.73**	1.65-1.82	**0.74**	0.68-0.80
65-74	**3.22**	3.05-3.40	**2.65**	2.51-2.80	**0.31**	0.28-0.35
75+	**7.87**	7.42-8.35	**4.65**	4.38-4.94	**0.34**	0.30-0.38
Sex 1991 (reference: female)						
Male	**0.90**	0.88-0.93	1.01	0.97-1.04	**0.78**	0.73-0.83
Ethnicity 1991 (reference: white)						
Not white	**1.39**	1.15-1.68	**1.79**	1.49-2.15	0.96	0.63-1.46
Has children in the household 2011 (reference: no)						
Yes	**0.61**	0.58-0.64	**0.64**	0.61-0.68	**0.63**	0.58-0.69
Highest-level educational qualification 2011 (reference: none)						
Non-degree	**0.65**	0.62-0.67	**0.58**	0.56-0.60	**0.80**	0.74-0.86
Degree	**0.52**	0.50-0.55	**0.41**	0.39-0.43	**0.77**	0.70-0.85
Housing tenure 2011 (reference: owner)						
Social renter	**3.03**	2.92-3.16	**3.25**	3.13-3.38	**4.11**	3.83-4.41
Private renter	**1.73**	1.61-1.86	**1.83**	1.70-1.96	**3.13**	2.77-3.52
Urban rural classification 2011 (reference: large urban area)						
Other urban area	1.00	0.97-1.04	**1.04**	1.00-1.08	0.94	0.87-1.01
Accessible small town	0.98	0.92-1.03	**0.93**	0.88-0.98	**0.82**	0.73-0.92
Remote small town	**0.86**	0.79-0.94	**0.86**	0.79-0.95	**0.58**	0.47-0.72
Accessible rural area	**0.85**	0.81-0.90	**0.81**	0.76-0.85	**0.69**	0.61-0.78
Remote rural area	**0.82**	0.76-0.89	**0.77**	0.71-0.84	**0.53**	0.43-0.64
Distance to the coastline 2011 (reference: =<1km)						
1< & =<5 km	0.96	0.91-1.02	0.97	0.91-1.03	0.95	0.84-1.08
5< & =<20km	1.02	0.96-1.08	1.02	0.96-1.08	0.99	0.88-1.12
>20 km	**1.13**	1.07-1.20	**1.23**	1.16-1.30	1.09	0.96-1.23

Table 5.5: Binary logistic regression models showing the associations between distance to the nearest forest and census health outcomes in 2011, controlling for sex, age group, ethnicity, children in the household, highest-level education, housing tenure, urban-rural classification and distance to the coastline. OR significant $p<0.05$ shown in boldface. Source: Scottish Longitudinal Study.

	Has a long-term illness 2011		Has bad general health 2011		Has a mental health condition 2011	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Distance to the nearest accessible forest (m) 2011 (reference: 0-<150m)						
150-<300	**1.06**	1.01-1.12	1.04	0.99-1.10	1.06	0.95-1.18
300-<500	**1.11**	1.05-1.17	**1.11**	1.05-1.16	1.05	0.94-1.17
500-<750	**1.12**	1.06-1.18	**1.11**	1.05-1.17	**1.12**	1.00-1.24
750-<1500	**1.12**	1.06-1.17	**1.10**	1.04-1.16	1.04	0.93-1.15
>=1500	**1.08**	1.00-1.16	**1.09**	1.01-1.18	1.02	0.87-1.20
Age group 2011 (reference: 38-49)						
50-64	**1.77**	1.69-1.86	**1.73**	1.65-1.82	**0.74**	0.68-0.80
65-74	**3.22**	3.05-3.40	**2.65**	2.51-2.80	**0.32**	0.28-0.35
75+	**7.87**	7.41-8.35	**4.65**	4.39-4.94	**0.34**	0.30-0.38
Sex 1991 (reference: female)						
Male	**0.90**	0.88-0.93	1.01	0.97-1.04	**0.78**	0.73-0.83
Ethnicity 1991						
Not white	**1.39**	1.15-1.68	**1.79**	1.49-2.15	**0.96**	0.64-1.46
Has children in the household 2011 (reference: no)						
Yes	**0.61**	0.58-0.64	**0.64**	0.61-0.68	**0.63**	0.58-0.69
Highest-level educational qualification 2011 (reference: none)						
Non-degree	**0.65**	0.62-0.67	**0.58**	0.56-0.60	**0.80**	0.74-0.86
Degree	**0.52**	0.50-0.55	**0.41**	0.39-0.43	**0.77**	0.70-0.85
Housing tenure 2011 (reference: owner)						
Social renter	**3.03**	2.92-3.16	**3.25**	3.13-3.38	**4.11**	3.83-4.42
Private renter	**1.73**	1.61-1.86	**1.83**	1.70-1.96	**3.13**	2.78-3.52
Urban rural classification 2011 (reference: large urban area)						
Other urban area	1.00	0.97-1.04	**1.04**	1.00-1.08	0.94	0.87-1.01
Accessible small town	0.98	0.92-1.03	**0.93**	0.88-0.99	**0.82**	0.73-0.92
Remote small town	**0.86**	0.79-0.95	**0.87**	0.79-0.95	**0.58**	0.47-0.72
Accessible rural area	**0.85**	0.81-0.90	**0.81**	0.76-0.85	**0.69**	0.61-0.78
Remote rural area	**0.82**	0.76-0.89	**0.77**	0.71-0.84	**0.53**	0.43-0.64
Distance to the coastline 2011 (reference: =<1km)						
1< & =<5 km	**0.96**	0.91-1.02	0.97	0.91-1.03	**0.96**	0.85-1.09
5< & =<20km	1.02	0.96-1.08	1.02	0.96-1.08	1.00	0.89-1.13
>20 km	**1.13**	1.07-1.20	**1.23**	1.16-1.30	1.10	0.97-1.25

Table 5.6: Binary logistic regression modelling showing the associations between distance to the nearest accessible forest and census health outcomes in 2011, controlling for sex, age group, ethnicity, children in the household, highest-level education, housing tenure, urban-rural classification and distance to the coastline. OR significant *$p<0.05$* shown in boldface. Source: Scottish Longitudinal Study.

In the bivariate analysis, significant relationships were found between forest proximity at different time points and the prescribing of antidepressants in 2011-2016 and attending a mental health outpatient appointment in 2011-2016. As above, each of these outcomes were modelled adjusting for demographic, socioeconomic and environmental characteristics. Final models are shown in Table 5.7 (all forests) and Table 5.8 (accessible forests only). Relationships between each of the health outcomes and distance to the nearest forest became insignificant when highest-level education and housing tenure were added to the model.

There were similar findings when considering accessible forests only. In the fully adjusted model, only one significant result was found, with people living 750-<1500m from the nearest accessible forest being 5% more likely than those living 0-<150m to be prescribed antidepressants (OR: 1.05, 95% CI: 1.01-1.10).

To summarise the findings so far, better forest proximity different time points were associated with better general health and some measures of mental health (reasons discussed in chapter 8). Multivariate analyses of the relationship between forests and health in 2011 suggest that forests could be more closely related to general health than mental health. However, thus far the investigation has been cross-sectional and exploratory, focusing on the relationship between forests and health at one point in time without taking into account each SLS member’s past and present levels of forest access, and directly examining whether better forest access trajectories lead to better health outcomes. The next set of analyses addresses this issue by identifying whether there are distinct patterns of forest access through time and whether these are associated the with the general and mental health outcomes examined.

	Prescribed antidepressants 2011-2016		Mental health outpatient 2011-2016	
	OR	**95% CI**	**OR**	**95% CI**
Distance to the nearest forest 2011 (m) (reference: 0-<150m)				
150-<300	1.01	0.97-1.06	1.00	0.91-1.10
300-<500	1.03	0.99-1.07	1.03	0.94-1.13
500-<750	1.03	0.98-1.07	1.02	0.93-1.12
750-<1500	1.04	0.99-1.09	1.04	0.94-1.15
>=1500	0.94	0.86-1.03	1.10	0.92-1.32
Age group 2011 (reference: 38-49)				
50-64	**0.89**	0.86-0.93	**0.67**	0.61-0.74
65-74	**0.82**	0.78-0.86	1.08	0.97-1.19
75+	**0.76**	0.72-0.80	**2.55**	2.32-2.81
Sex 1991 (reference: female)				
Male	**0.47**	0.46-0.48	**0.91**	0.86-0.97
Ethnicity 1991 (reference: white)				
Not white	**0.85**	0.71-1.01	**1.53**	1.08-2.17
Has children in the household 2011 (reference: no)				
Yes	**0.88**	0.85-0.92	**0.60**	0.54-0.67
Highest-level educational qualification 2011 (reference: none)				
Non-degree	**0.79**	0.77-0.82	**0.76**	0.71-0.82
Degree	**0.61**	0.59-0.64	**0.75**	0.69-0.82
Housing tenure 2011 (reference: owner)				
Social renter	**1.78**	1.71-1.84	**2.18**	2.04-2.33
Private renter	**1.44**	1.35-1.54	**1.72**	1.52-1.94
Urban rural classification 2011 (reference: Large urban area)				
Other urban area	**1.06**	1.02-1.09	1.06	0.99-1.13
Accessible small town	0.97	0.93-1.02	0.96	0.86-1.06
Remote small town	0.93	0.86-1.01	0.90	0.76-1.07
Accessible rural area	**0.88**	0.84-0.93	**0.88**	0.79-0.97
Remote rural area	**0.84**	0.79-0.91	0.99	0.86-1.15
Distance to the coastline 2011 (reference: =<1km)				
1< & =<5 km	1.01	0.96-1.07	0.99	0.89-1.10
5< & =<20km	1.03	0.98-1.08	0.95	0.86-1.06
>20 km	**1.06**	1.01-1.12	**0.84**	0.76-0.94

Table 5.7: Binary logistic regression modelling showing the associations between distance to the nearest forest and administrative health outcomes in 2011-2016, controlling for sex, age group, ethnicity, children in the household, highest-level education, housing tenure, urban-rural classification and distance to the coastline. OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

	Prescribed antidepressants 2011-2016		Mental health outpatient 2011-2016	
	OR	**95% CI**	**OR**	**95% CI**
Distance to the nearest accessible forest (m) 2011 (reference: 0-<150m)				
150-<300	1.01	0.96-1.06	1.01	0.92-1.12
300-<500	1.04	0.99-1.09	1.04	0.95-1.15
500-<750	1.04	0.99-1.09	1.01	0.91-1.11
750-<1500	**1.05**	1.01-1.10	1.05	0.95-1.16
>=1500	0.99	0.92-1.06	1.06	0.92-1.21
Age group 2011 (reference: 38-49)				
50-64	**0.89**	0.86-0.93	0.67	0.61-0.74
65-74	**0.82**	0.78-0.86	1.07	0.97-1.19
75+	**0.75**	0.72-0.80	**2.55**	2.32-2.81
Sex 1991 (reference: female)				
Male	**0.47**	0.46-0.48	**0.91**	0.86-0.97
Ethnicity 1991 (reference: white)				
Not white	0.85	0.71-1.01	**1.53**	1.08-2.17
Has children in the household 2011 (reference: no)				
Yes	**0.88**	0.85-0.92	**0.60**	0.54-0.67
Highest-level educational qualification 2011 (reference: none)				
Non-degree	**0.79**	0.77-0.82	**0.76**	0.71-0.82
Degree	**0.62**	0.59-0.64	**0.75**	0.69-0.82
Housing tenure 2011 (reference: owner)				
Social renter	**1.78**	1.71-1.84	**2.18**	2.04-2.33
Private renter	**1.44**	1.35-1.54	**1.72**	1.52-1.94
Urban rural classification 2011 (reference: Large urban area)				
Other urban area	**1.06**	1.02-1.09	1.06	0.99-1.13
Accessible small town	0.98	0.93-1.03	0.96	0.86-1.06
Remote small town	0.93	0.86-1.01	0.90	0.76-1.07
Accessible rural area	0.89	0.84-0.93	**0.87**	0.79-0.97
Remote rural area	0.85	0.79-0.91	0.99	0.86-1.15
Distance to the coastline 2011 (reference: =<1km)				
1< & =<5 km	1.01	0.96-1.07	0.98	0.88-1.10
5< & =<20km	1.03	0.98-1.08	0.95	0.85-1.05
>20 km	**1.06**	1.01-1.12	**0.84**	0.75-0.93

Table 5.8: Binary logistic regression modelling showing the associations between distance to the nearest accessible forest and administrative health outcomes in 2011-2016, controlling for sex, age group, ethnicity, children in the household, highest-level education, housing tenure, urban-rural classification and distance to the coastline. OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

5.3.3 Forest access trajectories and health

5.3.3.1 Identifying forest access trajectories

Forest access trajectories were identified using a modelling approach based on Latent Class Growth Modelling (LCGM) which classified SLS members with similar levels of forest access over time into the same groups. The frequencies of the actual SLS members classified into each trajectory group, and those estimated by the models are shown in Table 5.9. When all forests were considered, the study population was classified into three trajectory groups as shown in Fig.5.1. For those in Trajectory group 1, forest proximity did not change throughout the study period, and they continued to live 300-500m from the nearest forest, which has been regarded as within walking distance i.e. good access (see Chapter 2 for further discussion). For Trajectory group 2, forest access improved greatly between 1991 and 2001, and they remained living within 150m from the nearest forest. Lastly, those in Trajectory group 3 had steady improvement across the study period but did not live within 500m of forests at any of the three time points. Unsurprisingly, given the overall improvements seen in the earlier analysis, forest access did not worsen over time for any of the trajectory groups.

Trajectory groups		**Actual n (%)**	**Estimated n (%)**
All forests			
Label	Description		
1 – Remains 300-500m	1 – No change, remains 300-500m of nearest forest	12,338 (12.63)	17,383 (17.84)
2 – Improves to <150m	2 – Improvement to <150m of nearest forest	10,708 (10.96)	9,766 (10.01)
3 – Remains >500m	3 – Improvement but remains >500m of nearest forest	74,612 (76.40)	70,509 (72.15)
Accessible forests			
Label	Description		
1 – Remains 300-500m	1 – No change, remains 300-500m of nearest forest	11,099 (11.37)	15,039 (15.37)
2 – Improves to <150m	2 – Improvement to <150m of nearest forest	7,476 (7.66)	7,324 (7.49)
3 – Remains >=1500m	3 – No change, remains >=1500m of nearest forest	3,745 (3.83)	4,883 (5.01)
4 – Remains >500m	4 – Improvement but remains >500m of nearest forest	75,338 (77.14)	70,411 (72.13)

Table 5.9: Frequencies classified into each trajectory group. Source: Scottish Longitudinal Study.

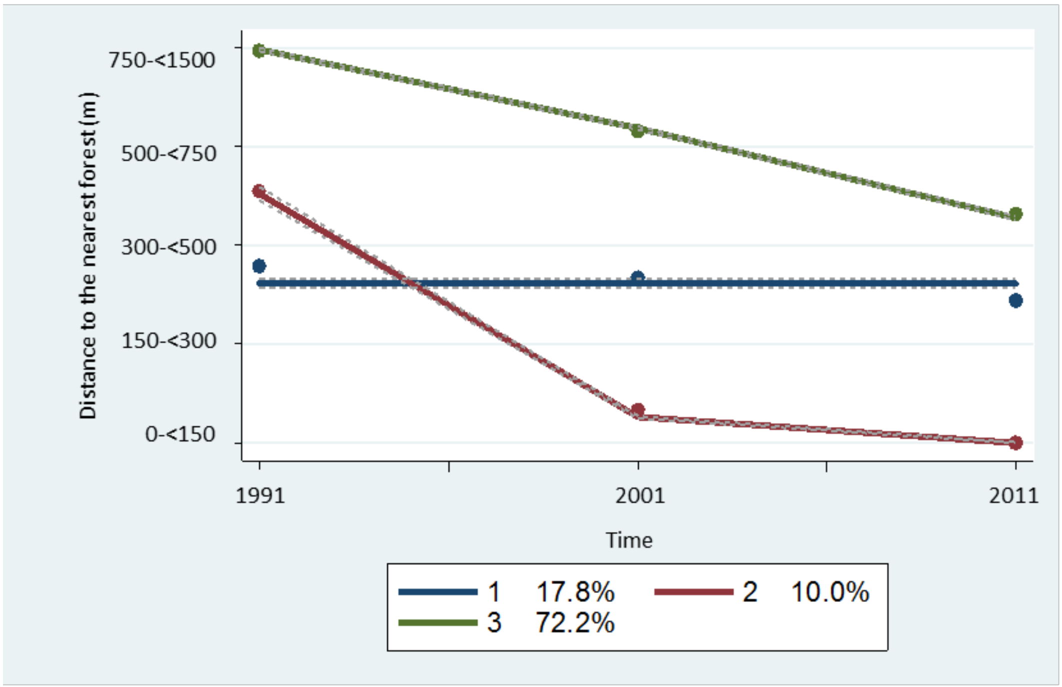


Fig. 5.1: Estimated trajectories of forest access (all forests), observed group means at each time point and estimated group percentages, with 95% confidence intervals, where declines in distance indicate improvements in forest access. Source: Scottish Longitudinal Study.

When the analysis was repeated for accessible forests only, four trajectory groups were found (Fig.5.2). For Trajectory group 1, there were no changes in forest proximity. Those in this group remained living within 500m of accessible forests. Similar to the previous model, Trajectory group 2 improved greatly then continued to have the best access to forests (living within 150m). For Trajectory group 3, forest access was the worst throughout the study period, with members estimated to live over 1500m from accessible forests. Lastly, although forest access improved for those in Trajectory group 4, this was not within recognised walking distance thresholds (300-500m).

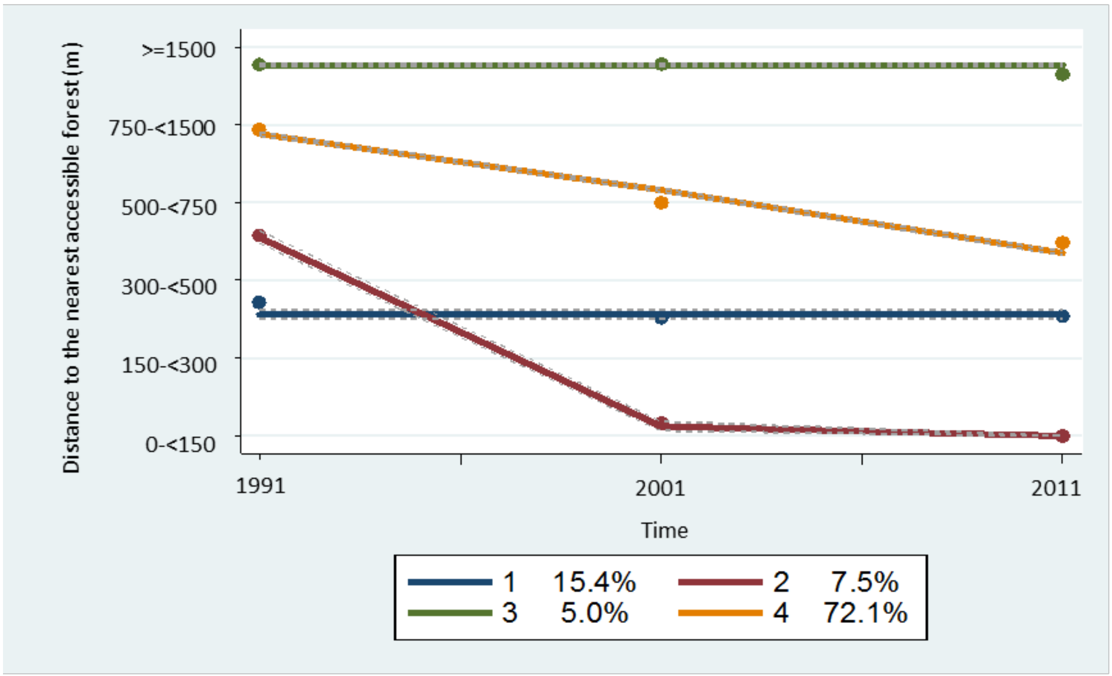


Fig. 5.2: Estimated trajectories of forest access (accessible forests only), observed group means at each time point and estimated group percentages, with 95% confidence intervals, where declines in distance indicate improvements in forest access. Source: Scottish Longitudinal Study.

5.3.3.2 Individual-level determinants of forest access trajectories

The association between trajectory group allocation and individual characteristics was examined. This allowed further exploration into the environmental justice issues identified in the previous chapter and into whether people of lower socioeconomic status were less likely to have better forest access trajectories. The specific factors tested were sex, age, ethnicity, highest-level education, housing tenure and whether there were children in the household, all of which were measured at the 1991 time point.

Bivariate correlations showed that all factors were significantly associated with trajectory group allocation, with the exception of ethnicity when examining trajectories in access to all forests. The values of Cramers V indicate that all were weak associations (Table 5.10). Regression models were used to identify which factors had the most explanatory power for each trajectory group. Final models for all forests are shown in Table 5.11 and for accessible forests only in Table 5.12.

	All forests		Accessible forests only	
	$\mathcal{X}^2$ p-value	**Cramers V**	**$\mathcal{X}^2$ p-value**	**Cramers V**
Sex 1991	0.00	0.01	0.03	0.01
Age group 1991	0.00	0.03	0.00	0.03
Ethnicity 1991	0.12	0.01	0.00	0.01
Highest-level education 1991	0.00	0.04	0.00	0.04
Housing tenure 1991	0.00	0.06	0.00	0.06
Children in household 1991	0.00	0.03	0.00	0.03

Table 5.10: Chi square associations between trajectory group and potential predictors. Source: Scottish Longitudinal Study.

As described in section 5.2.2.2, all variables were added together and those with no significant parameters were removed. When considering all forests, social renters were significantly less likely than home owners to be in Trajectory group 1 (OR: 0.79, 95% CI: 0.76-0.83) and Trajectory group 2 (OR: 0.65, 95% CI: 0.62-0.69) which experienced improved or consistently good forest access, and they were 44% more likely to have relatively poor forest access across the three time points (OR: 1.44, 95% CI: 1.39-1.49). Conversely, people with qualifications were significantly more likely than those with no qualifications to be in the groups with better forest access trajectories and less likely to be in the worse off trajectory group. Age group was also a significant predictor. For example, those aged 45-54 in 1991 were 37% more likely than those aged 18-30 to have improved forest access (OR:1.37, 95% CI: 1.29-1.45) and 19% less likely to be allocated to the trajectory group with the worst forest access trajectory (OR:0.81, 95% CI: 0.78-0.85).

	Trajectory group 1 Remains 300-500m		Trajectory group 2 Improves to <150m		Trajectory group 3 Remains >500m	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Age group 1991 (reference: 18-29)						
30-44	**1.05**	1.00-1.10	**1.24**	1.17-1.30	**0.87**	0.84-0.90
45-54	**1.07**	1.01-1.13	**1.37**	1.29-1.45	**0.81**	0.78-0.85
55+	1.05	0.98-1.12	**1.32**	1.23-1.42	**0.83**	0.79-0.88
Education 1991 (reference: none)						
Non-degree	**1.17**	1.11-1.25	**1.20**	1.13-1.28	**0.82**	0.78-0.86
Degree	1.01	0.94-1.09	**1.33**	1.24-1.42	**0.84**	0.80-0.89
Housing tenure 1991 (reference: owner)						
Social renter	**0.79**	0.76-0.83	**0.65**	0.62-0.69	**1.44**	1.39-1.49
Private renter	**1.39**	1.29-1.50	**1.25**	1.15-1.35	**0.72**	0.67-0.76
Has children in the household 1991 (reference: no)						
Yes	**1.15**	1.10-1.20	**1.13**	1.08-1.18	**0.86**	0.83-0.89

Table 5.11: Associations between individual-level characteristics and allocation to forest access trajectory groups (all forests). OR significant $p<0.05$ shown in boldface. Source: Scottish Longitudinal Study.

Similar results were found for accessible forests, with people of low socioeconomic status significantly more likely to be allocated to the groups with the worst forest access trajectories and those with higher socioeconomic status more likely to have better forest access trajectories. Similar associations with age were also found. Although very little variation in the sample, ethnicity was also identified as a significant predictor of improved forest access (to <150m from the nearest accessible forest). Non-white SLS members (0.65%) were 34% less likely than white SLS members to be in this group (OR: 0.66, 95% CI: 0.50-0.88).

	Trajectory group 1 Remains 300-500m		Trajectory group 2 Improves to <150m		Trajectory group 3 Remains >=1500m		Trajectory group 4 Remains >500m	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Age group 1991 (reference: 18-29)								
30-44	**1.10**	1.05-1.16	**1.31**	1.23-1.40	**1.19**	1.09-1.29	**0.82**	0.79-0.85
45-54	**1.15**	1.09-1.22	**1.47**	1.36-1.57	**1.11**	1.01-1.23	**0.78**	0.74-0.81
55+	**1.13**	1.05-1.21	**1.47**	1.36-1.60	**1.31**	1.18-1.46	**0.76**	0.72-0.80
Education 1991 (reference: none)								
Non-degree	**1.19**	1.11-1.26	**1.23**	1.14-1.32	0.99	0.89-1.10	**0.83**	0.79-0.87
Degree	**1.07**	1.00-1.15	**1.37**	1.27-1.49	**0.83**	0.72-0.94	**0.86**	0.82-0.91
Housing tenure 1991 (reference: owner)								
Social renter	**0.77**	0.74-0.81	**0.60**	0.56-0.64	**0.86**	0.80-0.93	**1.45**	1.39-1.50
Private renter	**1.37**	1.27-1.48	**1.31**	1.19-1.43	1.11	0.97-1.28	**0.73**	0.68-0.77
Has children in the household 1991 (reference: no)								
Yes	**1.16**	1.11-1.21	**1.13**	1.07-1.19			**0.88**	0.85-0.91
Ethnicity 1991 (reference: white)								
Not white	**0.66**	0.50-0.88			**0.48**	0.27-0.85	**1.52**	1.24-1.87

Table 5.12: Associations between individual-level characteristics and allocation to forest access trajectory groups (accessible forests only). OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

Lastly, the Wald test was used to identify the most important predictors of group trajectory membership, with those reporting the largest Wald statistic values having the most explanatory power. Results indicated that living in social rented accommodation was the most important predictor for all trajectory groups except for group 3 which was those who remained >1500m from the nearest accessible forest at each of the three time points (Table 5.13). For this group, being aged 55+ was the best predictor. The importance of each of the other factors tested varied between trajectory groups. For example, having a degree was the weakest predictor of being in Trajectory group 1 (all forests) but was one of the strongest predictors of being in Trajectory group 2 (all forests).

	Trajectory groups (all forests)			**Trajectory groups (accessible forests)**			
	1 Remains 300-500m	**2 Improves to <150m**	**3 Remains >500m**	**1 Remains 300-500m**	**2 Improves to <150m**	**3 Remains >=1500m**	**4 Remains >500m**
Age group 1991 (reference: 18-29)							
30-44	3.62	59.77***	50.56***	14.42***	69.96***	16.84***	101.61***
45-54	5.19*	101.64***	83.96***	22.01***	108.66***	4.55***	121.56***
55+	2.08	61.19***	46.49***	11.65***	85.00***	24.55***	108.52***
Education 1991 (reference: none)							
Non-degree	26.91***	31.44***	68.08***	27.68***	30.64***	0.04	55.95***
Degree	0.11	63.43***	38.78***	3.48	60.75***	7.84**	27.09***
Housing tenure 1991 (reference: owner)							
Social renter	104.27***	275.82***	404.75***	113.68***	271.77***	14.34***	403.1***
Private renter	73.07***	28.09***	112.55***	60.83***	31.32***	2.31	102.94***
Children in the household 1991 (reference: no)							
Yes	39.51***	27.18***	78.36***	41.08***	20.09***		50.57***
Ethnicity 1991 (reference: white)							
Not white				8.29**		6.31*	15.80***

Table 5.13: Wald test results indicating the most important predictors of forest access trajectory groups, where the factors with the higher Wald statistic values have more explanatory power. Source: Scottish Longitudinal Study. *p<0.05, **p<0.01, ***p<0.001.

5.3.3.3 Associations between forest access trajectories and health in 2011-2016

In the next stage, associations between forest access trajectories and health were explored using binary logistic regression modelling. Final models are shown in Table 5.14 for all forests and Table 5.15 for accessible forests only. The reference category for all models was the groups with improved forest access but remained >500m from the nearest forest (All forests: Trajectory group 3, Accessible forests: Trajectory group 4). People who had better forest access trajectories (All forests: Trajectory group 1 & 2; Accessible forests: Trajectory group 1 & 2) had reduced odds of having bad general health or a long-term illness in 2011. The largest effect was for those with improved forest access between 1991 and 2001 and lived <150m of the nearest accessible forests in 2001 and 2011. This group were 14% less likely to have bad general health in 2011 than those in Trajectory group 4 (OR: 0.86, 95% CI: 0.81-0.92). This group were also 8% less likely to be prescribed antidepressants in 2011-2016 (OR: 0.92, 95% CI: 0.87-0.97). However, people who had always lived >1500m from the nearest accessible forest (Accessible forests: Trajectory group 3) also had the same reduction in odds. Trajectory group 2 (for accessible forests only) were 17% less likely to report a mental health condition in 2011 which was the only significant finding for this particular outcome (OR: 0.83, 95% CI: 0.73-0.96). No significant associations were found between trajectories of forest access and attending mental health outpatient appointments in 2011-2016.

Trajectory groups	Has bad general health 2011		Has a mental health condition 2011		Has a long-term illness 2011		Prescribed antidepressants 2011-2016		Mental health outpatient 2011-2016	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
All forests (reference: Trajectory group 3 Remains >500m)										
1 Remains 300-500m	**0.90**	0.85-0.94	1.00	0.90-1.10	**0.91**	0.87-0.96	0.98	0.94-1.03	0.93	0.85-1.02
2 Improves to <150m	**0.89**	0.84-0.93	0.89	0.80-1.00	**0.88**	0.84-0.93	**0.95**	0.91-0.99	0.96	0.87-1.06

Table 5.14: Binary logistic regression modelling showing the associations between forest access trajectories (all forests) and health outcomes controlling for sex, age group, ethnicity, children in the household, highest-level education, housing tenure, urban-rural classification and distance to the coastline. OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

Trajectory groups	Has bad general health 2011		Has a mental health condition 2011		Has a long-term illness 2011		Prescribed antidepressants 2011-2016		Mental health outpatient 2011-2016	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Accessible forests (reference: Trajectory group 4 Remains >500m)										
1 Remains 300-500m	**0.92**	0.87-0.97	1.00	0.91-1.12	**0.90**	0.86-0.95	0.98	0.94-1.03	1.01	0.92-1.11
2 Improves to <150m	**0.86**	0.81-0.92	**0.83**	0.73-0.96	**0.88**	0.82-0.93	**0.92**	0.87-0.97	0.94	0.84-1.05
3 Remains >=1500m	1.02	0.94-1.10	0.91	0.76-1.09	0.98	0.91-1.07	**0.92**	0.86-0.99	1.04	0.90-1.21

Table 5.15: Binary logistic regression modelling showing the associations between forest access trajectories (accessible forests only) and health outcomes controlling for sex, age group, ethnicity, children in the household, highest-level education, housing tenure, urban-rural classification and distance to the coastline. OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

5.4 **Summary**

This chapter has applied cross-sectional and longitudinal statistical techniques to a large sample in order to investigate relationships between forest access and health through time; and for testing different social predictors of forest access trajectories. At individual time points, it was found that forest access was related to general health and some but not all of the mental health outcomes examined. Therefore, it is possible that forest access may be more closely related to particular mental illnesses or symptoms and less important for others (see Chapter 8 for discussion). The longitudinal analysis showed that people with lower socioeconomic status were more likely to have worse access throughout the study period and less likely to have better forest access trajectories. Focusing exclusively on the influence of forests on particular aspects of mental health, the next chapter explores relationships between forest access and administrative mental health outcomes over time using life course models of health.

6 Life course models of forest access and mental health

6.1 Introduction

The longitudinal analysis in the previous chapter identified that better forest access was related to particular aspects of mental health. For example, individuals with better forest access trajectories throughout the study period were less likely to be prescribed antidepressants and report a mental health condition in 2011-2016 than those with poorer forest access trajectories. This chapter further explores these relationships over time by using life course models of health. This allows investigation into whether the protective effect of forests accumulates over time or whether there are critical time periods in life when engaging with forests is particularly important for health at later time points. The chapter addresses the following aim and research questions:

To what extent do particular life course models of health describe associations between forest access and mental health in later life?

- At which stages of adulthood is forest access associated with mental health during 2011-2016?
- Is a greater accumulation of forest access between 1991 and 2011 associated with better mental health in 2011-2016?
- Do associations vary between different socio-demographic groups (sex, socioeconomic status, age, area-level deprivation and urban rural classification)?
- Is forest access associated with a reduction in inequalities in mental health?

The chapter consists of two main sections. Firstly, the data preparation and statistical techniques applied in order to investigate the above questions are described, including the life course model comparison framework, proposed by Mishra et al., (2009). Secondly, the results of the analyses are presented.

6.2 **Analysis**

6.2.1 Preparing variables

For this chapter only, the sample was stratified into three cohorts in order to identify potentially meaningful critical periods (Table 6.1). The cohorts were based on the four age categories already defined in the cross-sectional analysis. This reflected the age distribution in the sample and life stages and transition periods used in previous life course studies (Wadsworth et al. 2007).

Cohort group	Sample size	Age in 1991	Age in 2001	Age in 2011
1	28,509	18-29	28-39	38-49
2	38,274	30-44	40-54	50-64
3	30,875	45+	55+	65+

Table 6.1: Age of SLS members at each time point, by cohort group. Source: Scottish Longitudinal Study.

Stratifying the sample into smaller cohorts meant that there were too few numbers in each of the six forest distance categories (0-<150m, 150-<300m, 300-<500m, 500-<750m, 750-<1500m, >=1500m) required in order to conduct the life course analyses and explore interactions. Therefore, the forest proximity measures were recoded into three categories (0-<300m, 300-<750m, >=750m) which enabled large enough numbers in each distance band for the analysis. Having the 300m cut off point also allowed investigation of the 300m threshold. As explained in Chapter 2, 300m has been recognised as one of the important thresholds for mental health in the green space literature, with those living less than 300m having better mental health outcomes (Ekkel & de Vries 2017).

The mental health outcomes investigated were those identified as being significantly related to forest access in Chapter 5. These were in binary format and indicated whether or not the SLS member:

- was prescribed antidepressants in 2011-2016 (yes/no)
- was a mental health outpatient in 2011-2016 (yes/no)

Exploring both of these outcomes provided insight into the influence of forest access on a specific mental illness i.e. depression and also into mental illness generally. As described in Chapter 3, the mental health outpatient indicator identified those who had received specialist care for a range of mental health issues. The census outcome which indicated if the SLS member had a mental health condition in 2011 could not be examined in this chapter as there were too few cases in each cohort with this outcome.

6.2.2 Testing life course models of health

In Chapter 2, there was a discussion of the ways in which forest access may influence health over the life course. These were accumulation, critical periods and effect modification. In order to test whether a particular life course model described the relationship between forest access and mental health over time, a structured modelling approach was applied. This method, developed by Mishra et al. (2009), compared each of the three life course models with a saturated model, containing all life course models, to assess which of these best described patterns in the data.

For each life course model, a specification was proposed, and these are illustrated in Fig. 6.1. Firstly, two mechanisms of accumulation were proposed. In the strict accumulation model, it was assumed that forest proximity at each time point in the study period was contributing equally to health at the end of the study period. This was calculated as a summed total (i.e. distance to the nearest forest in 1991 + distance to the nearest forest in 2001 + distance to the nearest forest in 2011). Alternatively, in the relaxed accumulation model, forest proximity at each time point contributed to health at the end of the study period but not in equal proportions. Therefore, in the model specification, the forest proximity variables for each time point were added separately so that the effect of each one on mental health at the end of the study period was accounted for. Lastly, effect modification occurs when a critical period is identified but the effect of forest proximity at one time point can be altered by subsequent levels of forest proximity. These were specified in the model as the interaction between forest proximity at two time points (Murray et al. 2015).

The framework proposed by Mishra et al. (2009) was designed to suit analyses with binary exposure measures and continuous outcomes. Their original method used the partial F-test to formally compare the different model specifications against the saturated model, where an insignificant result ($p>0.05$) indicated that there was no difference between the life course model being tested and the saturated model in terms of fitting the data. This would indicate a good model fit and representation of the relationship between earlier forest proximity and mental health in 2011-2016. However, as the F-test is not suitable for comparing logistic regression models, the likelihood ratio test is used for this study instead, as suggested in Mishra et al., (2009) and Clayton & Hills (1993). In order to assess the quality of the models, Akaike Information Criteria (AIC) was also used. As described in Chapter 3, AIC is used to assess relative model fit based on the number of parameters in the model whereby models with smaller values of AIC better represent patterns in the data (Singer & Willett 2003). This additional indicator has been used in other studies which adopt Mishra's framework (Cherrie et al. 2018; Murray et al. 2015;). In this study, the life course model with an insignificant p-value (>0.05) and the smallest value of AIC was selected as the best-fitting model and therefore the best representation of the relationship between forest proximity and mental health over time.

In the previous chapter, results varied between models which considered people's proximity to all forests or just those which were publicly accessible. Therefore, the life course model comparison analysis was run separately for each forest proximity measure. Also, given the known sex disparities in prevalence of mental illnesses (World Health Organization 2018b), and particularly in depression, models were adjusted for sex. Differences in the reported mental health between men and women are further discussed in Chapter 8.

Throughout the analyses in this chapter, the reference category was the middle-distance band (300-<750m). This was chosen because it was the only forest distance category which was not the smallest across the three cohorts. It was important for the reference category to be consistent across the cohorts so that results could be compared.

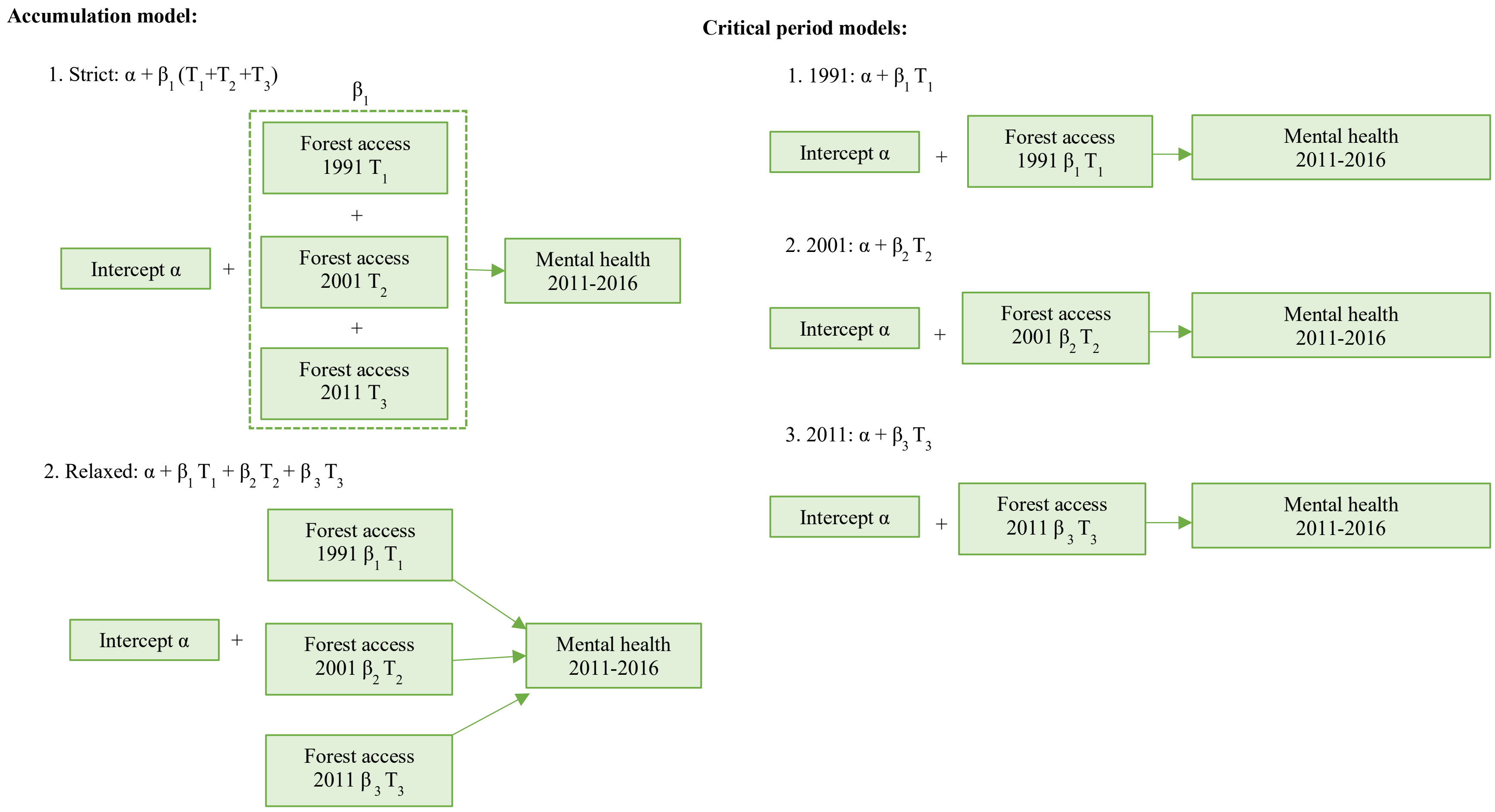
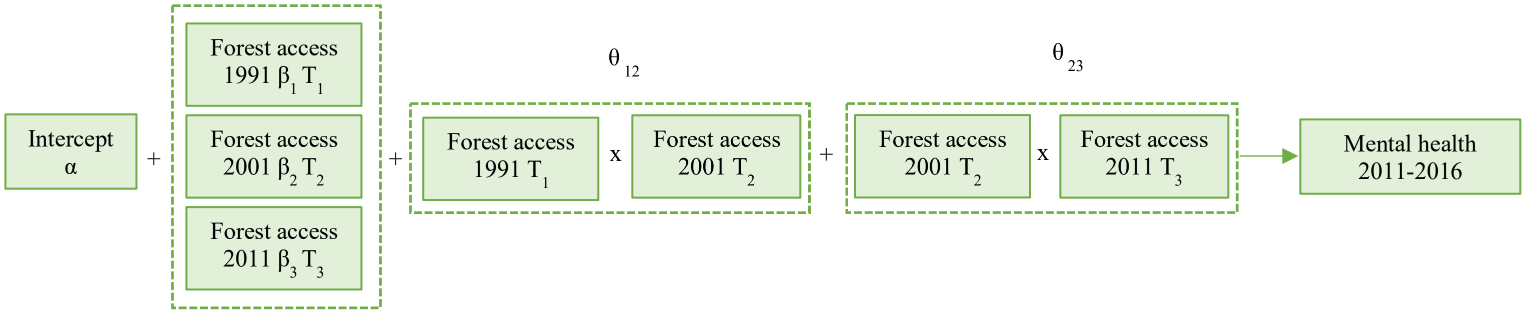


Fig. 6.1: Specifications for life course models of forest proximity and mental health. Diagrams and equations based on Cherrie et al. (2018) and Mishra et al. (2009).

Effect modification:

$$\alpha + \beta_1 T_1 + \beta_2 T_2 + \beta_3 T_3$$
$$+ \theta_{12} T_1 T_2 + \theta_{23} T_2 T_3$$



Saturated model:

$$\alpha + \beta_1 T_1 + \beta_2 T_2 + \beta_3 T_3$$
$$+ \theta_{12} T_1 T_2 + \theta_{13} T_1 T_3$$
$$+ \theta_{23} T_2 T_3 + \theta_{123} T_1 T_2 T_3$$

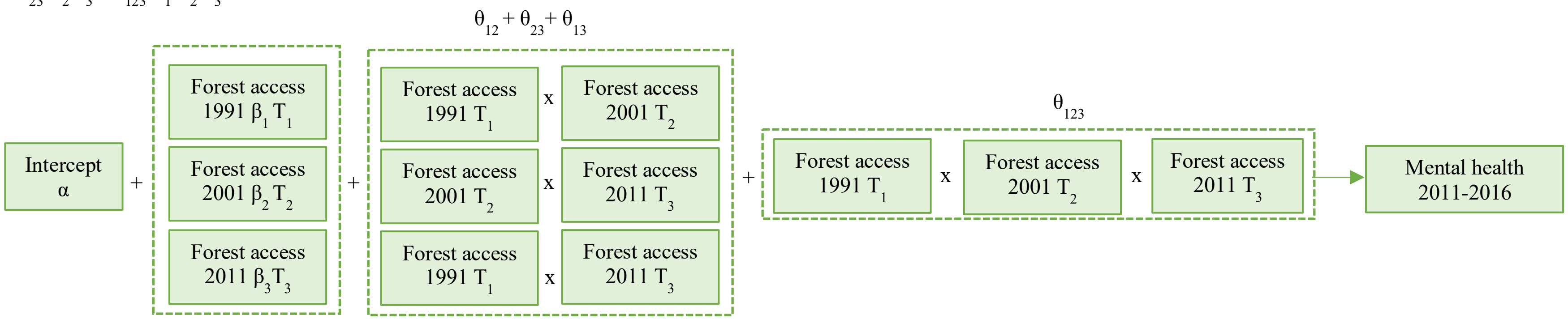


Fig. 6.1: continued.

6.2.3 Adjusted analyses

The life course models identified as the best fitting and therefore the most appropriate for describing the relationships between forests and mental health over time were adjusted for various sociodemographic factors in 1991. These factors included sex, whether or not there are children in the household, highest-level education, housing tenure, distance to the coastline (km) and urban-rural classification (2-fold). Ethnicity was not controlled for as there were too few sample members classified as 'non-white' to enable sufficient numbers in this category for the analysis. Controlling for these factors in 1991, at the start of the study period, was appropriate for this set of analyses as it allowed the approach to confounding to be consistent between each life course model selected. Sociodemographic factors in 1991 could potentially influence forest proximity at any of three time points and mental health in 2011-2016, regardless of the life course model selected. Maintaining a consistent approach to confounding throughout this chapter was essential so that comparisons between cohorts, population groups, health outcomes and forest types could be made. For sensitivity, models were run containing the confounders in 1991 and 2001; 2001 and 2011; and 1991 and 2011. However, each of these sets of models were problematic due to the same variables at different time points being highly correlated. Whether or not the SLS member had the mental health outcome of interest before 2011 was also considered a potential confounder. This was because previous mental health was thought to be a strong predictor of mental health in 2011-2016 and could also be a predictor of forest proximity whereby people with poor mental health might choose to live closer to forests for possible therapeutic benefits.

As described in Chapter 5, potential confounders were added to the models separately whereby demographic, socioeconomic and environmental indicators were added in three steps. Additionally, whether or not the SLS member had the outcome before 2011 was added to the model in a fourth step.

6.2.4 Stratified analyses

In order to explore differences in life course models of forest proximity and mental health between population groups, the final models were stratified by sex, highest-level education, Carstairs deprivation index (quintile) and urban rural classification (2-fold) in 1991.

6.2.5 Testing and exploring interactions

Interactions between each of four variables above and life course models of forest proximity were tested using the Wald Test. This showed whether the differences in associations across population groups were statistically significant. Significant interactions were further explored using the 'margins' command in Stata. This command provided the predicted probability of having the outcome (Kohler & Kreuter 2012) for all combinations of forest proximity and the population grouping variable being tested. Where the accumulation (strict) model was selected, average marginal effects were calculated instead of probabilities. This allowed the cumulative forest distance score to be treated as a continuous variable. In this study, average marginal effects represent the difference in the probability of having the mental health outcome compared to the reference group. Where confidence intervals crossed zero, this indicated that differences between groups were not significant.

6.3 **Results**

6.3.1 Selecting life course models

As specified in Section 6.2, a model comparison framework proposed by Mishra et al. (2009) was used to select the life course models which best described the relationship between forest proximity and mental health through time. Two mental health outcomes were investigated: whether or not the SLS member was prescribed antidepressant medication during 2011-2016; and whether or not they were a mental health outpatient in the same time period. Table 6.2 and Table 6.3 show a summary of the life course models selected and the results of the likelihood ratio tests when each model was compared with the saturated model, respectively. Selected models varied between cohorts, forest type and mental health outcomes. For cohort 2, it was found that the effect of forest proximity (all forests) in 1991 on the prescribing of antidepressants was modified by level of forest proximity in 2001, when cohort members were aged 40-54 (AIC=47074.01, p=0.15) (Table 6.3), whereas, the accumulation (strict) model was identified as the best for describing the relationship between forest proximity (all and accessible only) and the likelihood of being an outpatient (All forests AIC=11004.24, p=0.57; accessible forests only AIC=11005.75, p=0.49) (Table 6.3). For this cohort, no model was selected which described the relationship between proximity to publicly accessible forests and prescribing of antidepressants over time, as all life course models were found to be significantly different from the saturated model.

Furthermore, for those in cohort 1 (aged 38-49 in 2011), although critical time period models were identified as the best-fitting across both outcomes and forest types, the time point identified as important for forest proximity was not consistent (Table 6.2). Being aged 38-49 (2011) was recognised as a critical period for both mental health outcomes when only considering accessible forests. However, when proximity to all forests was considered, results varied between the two outcomes: level of forest proximity was most important in 2011 for attending a mental health outpatient appointment in 2011-2016 (AIC=9137.24, p=0.15), whereas earlier levels of forest proximity in 2001, when cohort members were aged 28-39 years (AIC=34767.40, p=0.46), was identified as the critical period for the prescribing of antidepressants (Table 6.3).

	All forests		Accessible forests only	
	Prescribed antidepressants 2011-2016	Mental health outpatient 2011-2016	Prescribed antidepressants 2011-2016	Mental health outpatient 2011-2016
Cohort 1	Critical time period 2001	Critical time period 2011	Critical time period 2011	Critical time period 2011
Cohort 2	Effect modification 1991-2001	Accumulation (strict)	None selected	Accumulation (strict)
Cohort 3	Accumulation (strict)	Accumulation (strict)	Critical time period 2001	Accumulation (strict)

Table 6.2: Summary of selected life course models. Source: Scottish Longitudinal Study.

	All forests				Accessible forests only			
	Prescribed antidepressants 2011-2016		Mental health outpatient 2011-2016		Prescribed antidepressants 2011-2016		Mental health outpatient 2011-2016	
Cohort 1	**AIC**	**p**	**AIC**	**p**	**AIC**	**p**	**AIC**	**p**
Accumulation (strict)	34767.82	0.39	9141.58	0.05	34767.53	0.11	9140.73	0.07
Accumulation (relaxed)	34771.50	0.45	9143.38	0.08	34766.09	0.31	9142.51	0.11
Critical time period 1991	34773.13	0.19	9145.77	0.02	34772.70	0.04	9145.83	0.03
Critical time period 2001	34767.40	0.46	9144.55	0.03	34766.99	0.14	9144.89	0.03
Critical time period 2011	34767.42	0.46	9137.24	0.15	34761.61	0.34	9135.85	0.21
Effect modification 1991-2001	34773.27	0.47	9151.80	0.01	34774.18	0.08	9152.74	0.01
Effect modification 2001-2011	34772.24	0.54	9137.90	0.35	34766.88	0.36	9139.99	0.26
Cohort 2								
Accumulation (strict)	47089.34	0.00	11004.24	0.57	47091.06	0.00	11005.75	0.49
Accumulation (relaxed)	47075.84	0.07	11011.28	0.45	47080.52	0.00	11012.49	0.38
Critical time period 1991	47085.71	0.00	11005.93	0.53	47089.52	0.00	11007.46	0.44
Critical time period 2001	47102.99	0.00	11008.74	0.37	47105.48	0.00	11009.25	0.35
Critical time period 2011	47118.25	0.00	11009.77	0.32	47115.54	0.00	11009.47	0.34
Effect modification 1991-2001	47074.01	0.15	11012.18	0.52	47076.30	0.01	11011.99	0.54
Effect modification 2001-2011	47102.71	0.00	11014.37	0.38	47092.61	0.00	11012.35	0.51
Cohort 3								
Accumulation (strict)	38953.57	0.52	18571.00	0.14	38953.64	0.34	18575.50	0.49
Accumulation (relaxed)	38957.91	0.57	18576.46	0.11	38956.93	0.43	18582.03	0.40
Critical time period 1991	38956.45	0.41	18574.64	0.08	38956.76	0.25	18578.83	0.36
Critical time period 2001	38954.22	0.54	18576.46	0.05	38953.04	0.43	18578.39	0.39
Critical time period 2011	38962.77	0.15	18581.32	0.02	38962.60	0.08	18583.53	0.17
Effect modification 1991-2001	38955.52	0.85	18572.65	0.32	38956.42	0.59	18579.86	0.67
Effect modification 2001-2011	38961.21	0.48	18585.68	0.02	38958.34	0.46	18589.52	0.14

Table 6.3: Results of likelihood ratio tests when each life course model of forest proximity and mental health was compared to the saturated model. Insignificant p-values (p>0.05) and smaller values of AIC indicate better model-fit. Source: Scottish Longitudinal Study.

6.3.2 Associations between forest access and mental health

Each of the selected models were adjusted for demographic, socioeconomic and environmental factors, and whether or not the SLS member had the outcome of interest before 2011. When all were added to the models, two significant associations were found. Firstly, as shown in Table 6.4, for those in cohort 2, those living >=750m from the nearest forest (aged 30-44) were 11% more likely to be prescribed antidepressants in 2011-2016, compared with those living 300-<750m (OR=1.11, 95% CI=1.01-1.22). However, the interaction terms in the model (representing the effect modification model) were not significant, indicating that this effect had been diminished by level of forest access in 2001. Secondly, as shown in Table 6.5, for cohort 3 (aged 65+ in 2011) the risk of being a mental health outpatient in 2011-2016 increased by 2% as the cumulative forest distance score increased (OR=1.02, 95% CI=1.00-1.05). As shown in Table 6.5, this result was identical when only accessible forests were considered (OR=1.02, 95% CI=1.00-1.04).

All forests					
Prescribed antidepressants 2011-2016			**Mental health outpatient 2011-2016**		
Selected life course model	**OR**	**95% CI**	**Selected life course model**	**OR**	**95% CI**
Cohort 1					
Critical time period 2001			Critical time period – 2011		
Distance to the nearest forest(m)			Distance to the nearest forest(m)		
0-<300m	0.97	0.90-1.05	0-<300	0.96	0.81-1.14
>=750m	0.97	0.90-1.04	>=750	0.94	0.80-1.09
Cohort 2					
Effect modification 1991-2001			Accumulation (strict)		
Distance to the nearest forest (m) 1991			Summed distance to the nearest forest	1.00	0.97-1.04
0-<300	1.13	0.97-1.32			
>=750	**1.11**	1.01-1.22			
Distance to the nearest forest (m) 2001					
0-<300	1.02	0.91-1.14			
>=750	1.00	0.87-1.14			
Distance to the nearest forest 1991 x Distance to the nearest forest 2001					
0-<300#0-<300	0.81	0.67-1.00			
0-<300#>=750	1.07	0.83-1.39			
>=750#0-<300	0.97	0.84-1.13			
>=750#>=750	0.98	0.84-1.14			
Cohort 3					
Accumulation (strict)			Accumulation (strict)		
Summed distance to the nearest forest	1.00	0.98-1.01	Summed distance to the nearest forest	**1.02**	1.00-1.05

Table 6.4: The associations between the selected life course models of forest proximity (all forests) and mental health outcomes for each cohort adjusted for sex, children in the household, highest-level education, housing tenure, urban-rural classification, distance to the nearest coastline and whether SLS member had the outcome previous to 2011. OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

Accessible forests only					
Prescribed antidepressants 2011-2016			**Mental health outpatient 2011-2016**		
Selected life course model	**OR**	**95% CI**	**Selected life course model**	**OR**	**95% CI**
Cohort 1					
Critical time period 2011			Critical time period – 2011		
Distance to the nearest forest(m)			Distance to the nearest forest(m)		
0-<300m	0.96	0.90-1.03	0-<300	0.89	0.76-1.05
>=750m	0.97	0.90-1.05	>=750	1.10	0.93-1.29
Cohort 2					
			Accumulation (strict)		
None selected			Summed distance to the nearest forest	1.00	0.97-1.04
Cohort 3					
Critical time period 2001			Accumulation (strict)		
Distance to the nearest forest(m)			Summed distance to the nearest forest	**1.02**	1.00-1.04
0-<300m	0.98	0.91-1.05			
>=750m	0.99	0.92-1.05			

Table 6.5: The associations between the selected life course models of forest proximity (accessible forests only) and mental health outcomes for each cohort adjusted for sex, children in the household, highest-level education, housing tenure, urban-rural classification, distance to the nearest coastline and whether SLS member had the outcome previous to 2011.
OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

6.3.3 Differences between population groups

The fully adjusted models were stratified by sex, highest-level education, Carstairs deprivation index (quintiles) and urban-rural classification (2-fold) in order to investigate whether the relationships between life course models of forest proximity and mental health varied between these sociodemographic groups.

Across the cohorts, substantial differences in results were found for each of these groupings, most notably between males and females, with forests having a protective effect for women and a negative or null effect for men. As shown in Table 6.6, females in cohort 1 (aged 38-49 in 2011) who lived 0-<300m from the nearest accessible forest in 2011 had reduced odds of being a mental health outpatient in 2011-2016 (OR=0.79, 95% CI=0.65-0.98), compared to those who lived 300-<750m. Differences by sex were also identified in cohort 3 (aged 65+ in 2011) (Table 6.8). Men who lived within 300m of an accessible forest in 2001 (aged 55+) were 15% more likely to be prescribed antidepressants in 2011-2016 than those who lived 300-<750m whereas women who lived within 300m were 13% less likely (males OR=1.15, 95% CI=1.03-1.28; females OR=0.87, 95% CI=0.79-0.95). A similar effect was found when the mental health outpatient outcome was examined. For both forest types, a woman's likelihood of being a mental health outpatient increased by 3% as cumulative forest distance increased over the three time points (all forests OR=1.03, 95% CI=1.00-1.07; accessible forests only OR=1.03, 95% CI=1.00-1.06). On the other hand, for men, the chance of being prescribed antidepressants reduced as cumulative forest distance score increased (OR=0.97, 95% CI=0.94-0.99).

Findings also suggested that levels of forest access at different time points might be important for the later mental health of those with low individual-level socioeconomic status and those living in deprived areas. In cohort 1 (Table 6.6), those living in the most deprived areas of Scotland and who lived 0-<300m from the nearest forest in 2011 were 29% less likely to be a mental health outpatient in 2011-2016 (OR=0.71, 95% CI=0.53-0.95) than those living 300-<750m. Also, in cohort 3, (Table 6.8), the chance of being a mental health outpatient increased with cumulative forest distance score when all forests and accessible forests only were considered (all forests OR=1.06, 95% CI=1.00-1.12; accessible forests only OR=1.06, 95% CI=1.00-1.12). Those in Cohort 2, without qualifications, and who lived 0-<300m from the nearest forest in 1991 (aged 30-44) and 2001 (aged 40-54), were 26% less likely to be prescribed antidepressants in 2011-2016 than those who lived 300-<750m at both time points (OR=0.74, 95% CI=0.59-0.93).

Cohort 1	All forests				Accessible forests			
	Prescribed antidepressants 2011-2016		**Mental health outpatient 2011-2016**		**Prescribed antidepressants 2011-2016**		**Mental health outpatient 2011-2016**	
	Critical period: Distance to the nearest forest (2001)		**Critical period: Distance to the nearest forest (2011)**		**Critical period: Distance to the nearest forest (2011)**		**Critical period: Distance to the nearest forest (2011)**	
	0-<300m OR (95% CI)	**>=750m OR (95% CI)**	**0-<300m OR (95% CI)**	**>=750m OR (95% CI)**	**0-<300m OR (95% CI)**	**>=750m OR (95% CI)**	**0-<300m OR (95% CI)**	**>=750m OR (95% CI)**
Sex								
Females	1.00	1.04	0.94	0.98	1.00	1.01	**0.79**	1.11
	(0.91-1.10)	(0.95-1.13)	(0.75-1.18)	(0.80-1.19)	(0.92-1.10)	(0.92-1.11)	(0.65-0.98)	(0.90-1.38)
Males	0.92	**0.86**	1.00	0.89	0.89	0.92	1.06	1.09
	(0.81-1.04)	(0.77-0.97)	(0.76-1.30)	(0.70-1.12)	(0.80-1.00)	(0.82-1.04)	(0.83-1.36)	(0.85-1.41)
Highest-level education								
No qualifications	1.03	1.01	0.87	0.98	0.96	0.98	0.90	1.08
	(0.92-1.15)	(0.94-1.09)	(0.74-1.01)	(0.81-1.19)	(0.89-1.03)	(0.90-1.06)	(0.76-1.07)	(0.91-1.28)
Non-degree	1.21	1.05	1.23	2.02	0.91	0.89	0.98	1.85
	(0.83-1.77)	(0.80-1.39)	(0.64-2.35)	(0.94-4.34)	(0.70-1.18)	(0.67-1.20)	(0.49-1.98)	(0.93-3.69)
Degree	1.42	1.00	0.72	0.95	1.02	1.03	0.73	0.89
	(0.86-2.35)	(0.70-1.43)	(0.36-1.46)	(0.36-2.54)	(0.75-1.39)	(0.72-1.48)	(0.35-1.52)	(0.38-2.09)
Carstairs deprivation index (quintiles)								
1 (least deprived)	1.19	1.03	0.72	1.16	0.93	1.02	0.66	0.87
	(0.96-1.48)	(0.86-1.23)	(0.47-1.10)	(0.70-1.91)	(0.78-1.11)	(0.84-1.25)	(0.42-1.04)	(0.55-1.37)
2	1.08	1.07	1.05	1.39	0.99	0.99	1.24	1.37
	(0.87-1.34)	(0.91-1.25)	(0.73-1.50)	(0.89-2.18)	(0.84-1.15)	(0.83-1.18)	(0.85-1.82)	(0.91-2.07)
3	**1.29**	1.10	0.93	1.01	0.91	1.01	0.83	1.09
	(1.02-1.62)	(0.94-1.28)	(0.67-1.30)	(0.66-1.54)	(0.78-1.05)	(0.86-1.19)	(0.58-1.19)	(0.75-1.58)
4	0.93	**0.83**	1.08	1.00	0.97	0.92	1.16	1.20
	(0.72-1.20)	(0.71-0.96)	(0.79-1.47)	(0.68-1.47)	(0.84-1.12)	(0.79-1.08)	(0.83-1.62)	(0.85-1.70)
5 (most deprived)	0.79	0.99	**0.71**	0.85	1.01	0.96	0.74	1.08
	(0.58-1.06)	(0.84-1.17)	(0.53-0.95)	(0.60-1.20)	(0.87-1.17)	(0.82-1.13)	(0.54-1.02)	(0.79-1.46)
Urban rural classification (2-fold)								
Urban	1.07	1.02	0.90	1.02	0.96	0.98	0.91	1.07
	(0.95-1.21)	(0.94-1.10)	(0.77-1.06)	(0.84-1.24)	(0.89-1.04)	(0.90-1.06)	(0.76-1.08)	(0.90-1.28)
Rural	0.99	0.96	0.72	0.97	0.94	0.93	0.82	1.21
	(0.81-1.22)	(0.80-1.16)	(0.49-1.07)	(0.60-1.59)	(0.78-1.13)	(0.76-1.14)	(0.53-1.27)	(0.79-1.86)

Table 6.6: Fully adjusted models showing associations between the selected life course models of forest proximity and mental health outcomes for cohort 1, stratified by sex, highest-level education, Carstairs deprivation index (quintiles) and urban rural classification (2-fold). OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

Cohort 2	All forests Prescribed antidepressants 2011-2016 Effect modification (1991-2001)							
	0-<300m OR (95% CI)	**>=750m OR (95% CI)**	**0-<300m OR (95% CI)**	**>=750m OR (95% CI)**	**0-<300#0-<300 OR (95% CI)**	**0<300#>=750 OR (95% CI)**	**>=750#0-<300 OR (95% CI)**	**>=750#>=750 OR (95% CI)**
Sex								
Females	1.17	1.10	0.96	0.95	0.79	1.07	1.05	1.02
	(0.96-1.43)	(0.97-1.25)	(0.83-1.12)	(0.79-1.13)	(0.61-1.03)	(0.76-1.50)	(0.86-1.28)	(0.83-1.25)
Males	1.08	1.13	1.10	1.07	0.84	1.07	0.88	0.92
	(0.85-1.37)	(0.98-1.31)	(0.92-1.31)	(0.87-1.31)	(0.62-1.15)	(0.73-1.59)	(0.69-1.10)	(0.73-1.17)
Highest-level education								
No qualifications	**1.18**	1.08	1.02	1.00	**0.74**	0.96	0.98	0.96
	(1.00-1.40)	(0.98-1.20)	(0.90-1.16)	(0.87-1.16)	(0.59-0.93)	(0.72-1.29)	(0.83-1.16)	(0.81-1.13)
Non-degree	1.00	**1.37**	0.91	1.17	1.31	1.08	1.00	0.89
	(0.63-1.60)	(1.01-1.87)	(0.63-1.30)	(0.78-1.78)	(0.71-2.40)	(0.51-2.29)	(0.63-1.60)	(0.55-1.44)
Degree	0.84	1.15	1.21	0.64	0.96	**3.51**	0.80	1.60
	(0.46-1.53)	(0.79-1.67)	(0.78-1.86)	(0.35-1.18)	(0.45-2.03)	(1.33-9.28)	(0.46-1.38)	(0.81-3.17)
Carstairs deprivation index (quintiles)								
1 (least deprived)	**1.33**	**1.28**	1.02	1.14	0.78	0.92	0.98	0.76
	(1.02-1.73)	(1.04-1.56)	(0.82-1.27)	(0.88-1.48)	(0.55-1.11)	(0.59-1.43)	(0.73-1.33)	(0.56-1.05)
2	1.01	1.08	1.05	1.06	0.83	1.20	0.96	0.97
	(0.73-1.39)	(0.88-1.32)	(0.83-1.33)	(0.81-1.40)	(0.55-1.25)	(0.71-2.04)	(0.70-1.32)	(0.70-1.34)
3	0.98	0.97	1.07	0.87	0.97	1.22	1.00	1.26
	(0.68-1.41)	(0.78-1.20)	(0.83-1.38)	(0.64-1.19)	(0.61-1.55)	(0.65-2.29)	(0.71-1.40)	(0.89-1.80)
4	**1.57**	1.22	0.87	0.97	0.61	0.70	1.11	0.93
	(1.05-2.33)	(0.98-1.51)	(0.64-1.17)	(0.70-1.33)	(0.36-1.06)	(0.34-1.43)	(0.76-1.61)	(0.65-1.33)
5 (most deprived)	0.81	0.93	1.15	0.88	1.02	1.76	0.77	1.14
	(0.49-1.34)	(0.73-1.19)	(0.83-1.61)	(0.60-1.29)	(0.52-1.99)	(0.79-3.96)	(0.51-1.16)	(0.75-1.74)
Urban rural classification (2-fold)								
Urban	1.14	**1.15**	1.01	1.04	0.80	1.04	0.98	0.92
	(0.95-1.37)	(1.04-1.28)	(0.88-1.15)	(0.89-1.21)	(0.63-1.02)	(0.77-1.40)	(0.83-1.16)	(0.77-1.09)
Rural	1.07	0.91	1.03	0.87	0.85	1.21	0.96	1.30
	(0.79-1.43)	(0.72-1.17)	(0.81-1.31)	(0.64-1.16)	(0.58-1.23)	(0.73-2.02)	(0.65-1.40)	(0.89-1.89)

Table 6.7: Fully adjusted models showing associations between the selected life course models of forest proximity and mental health outcomes for cohort 2, stratified by sex, highest-level education, Carstairs deprivation index (quintiles) and urban rural classification (2-fold). OR significant $p<0.05$ shown in boldface. Source: Scottish Longitudinal Study.

Cohort 2	All forests Mental health outpatient 2011-2016 Accumulation (strict) OR (95% CI)	Accessible forests Mental health outpatient 2011-2016 Accumulation (strict) OR (95% CI)
Sex		
Females	1.02 (0.97-1.07)	1.02 (0.97-1.07)
Males	0.98 (0.93-1.04)	0.99 (0.94-1.05)
Highest-level education		
No qualifications	0.99 (0.96-1.03)	1.00 (0.96-1.04)
Non-degree	1.06 (0.92-1.21)	1.05 (0.91-1.20)
Degree	1.10 (0.96-1.27)	1.08 (0.93-1.25)
Carstairs deprivation index (quintiles)		
1 (least deprived)	1.03 (0.94-1.12)	1.02 (0.94-1.12)
2	0.94 (0.86-1.02)	0.95 (0.87-1.03)
3	1.01 (0.94-1.09)	1.03 (0.95-1.11)
4	1.00 (0.93-1.08)	0.98 (0.90-1.06)
5 (most deprived)	1.02 (0.94-1.10)	1.01 (0.94-1.10)
Urban rural classification (2-fold)		
Urban	1.00 (0.96-1.04)	1.00 (0.96-1.05)
Rural	1.01 (0.93-1.10)	1.01 (0.93-1.10)

Table 6.7: continued. Source: Scottish Longitudinal Study.

Cohort 3	All forests: Prescribed antidepressants 2011-2016	All forests: Mental health outpatient 2011-2016	Accessible forests only: Prescribed antidepressants 2011-2016		Accessible forests only: Mental health outpatient 2011-2016
	Accumulation (strict)	Accumulation (strict)	Critical period: Distance to the nearest forest (2001) 0-<300m	Critical period: Distance to the nearest forest (2001) >=750m	Accumulation (strict)
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Sex					
Females	1.02 (0.99-1.04)	**1.03** (1.00-1.07)	**0.87** (0.79-0.95)	0.98 (0.90-1.07)	**1.03** (1.00-1.06)
Males	**0.97** (0.94-0.99)	1.01 (0.97-1.05)	**1.15** (1.03-1.28)	0.99 (0.89-1.10)	1.01 (0.97-1.04)
Highest-level education					
No qualifications	1.00 (0.98-1.02)	1.02 (0.99-1.05)	1.03 (0.96-1.11)	1.05 (0.98-1.14)	1.01 (0.99-1.04)
Non-degree	0.95 (0.90-1.01)	1.03 (0.94-1.12)	1.13 (0.91-1.39)	0.90 (0.70-1.15)	1.03 (0.95-1.12)
Degree	1.02 (0.94-1.11)	1.11 (0.99-1.25)	1.13 (0.91-1.39)	0.90 (0.70-1.15)	1.03 (0.95-1.12)
Carstairs deprivation index (quintiles)					
1 (least deprived)	0.98 (0.95-1.01)	0.98 (0.93-1.03)	0.98 (0.85-1.12)	0.91 (0.79-1.05)	0.97 (0.93-1.02)
2	0.99 (0.96-1.03)	**1.06** (1.00-1.11)	1.05 (0.90-1.22	1.10 (0.95-1.27)	1.04 (0.98-1.09)
3	0.99 (0.96-1.03)	0.99 (0.94-1.05)	0.92 (0.79-1.08)	0.92 (0.80-1.06)	0.99 (0.94-1.05)
4	1.00 (0.96-1.03)	**1.06** (1.00-1.12)	0.94 (0.79-1.12)	0.98 (0.85-1.13)	**1.06** (1.00-1.12)
5 (most deprived)	1.01 (0.96-1.06)	1.01 (0.95-1.08)	1.02 (0.82-1.26)	1.03 (0.87-1.22)	1.00 (0.94-1.07)
Urban rural classification (2-fold)					
Urban	1.00 (0.98-1.02)	**1.02** (1.00-1.05)	0.98 (0.90-1.06)	1.00 (0.93-1.07)	**1.02** (1.00-1.05)
Rural	0.98 (0.94-1.01)	1.03 (0.97-1.09)	0.97 (0.83-1.13)	0.91 (0.77-1.08)	0.99 (0.94-1.05)

Table 6.8: Fully adjusted models showing associations between the selected life course models of forest proximity and mental health outcomes for cohort 3, stratified by sex, highest-level education, Carstairs deprivation index (quintiles) and urban rural classification (2-fold). OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

6.3.4 Testing and exploring interactions between sociodemographic groups and forest access

The significance of the interactions between selected life course models of forest proximity and sociodemographic groups were tested. Results are summarised in Table 6.9. For cohort 1, the relationship between the selected life course model of forest proximity (all forests) and being prescribed antidepressants was significantly different between males and females ($p<0.001$), education levels ($p< 0.001$) and deprivation quintiles ($p<0.001$). When examining accessible forests only, there were significant differences by sex and highest-level education only ($p<0.01$).

For cohort 2, the relationship between the accumulation of forest proximity and being a mental health outpatient varied significantly by highest-level education ($p<0.001$) and deprivation levels ($p<0.001$) when all forests and accessible forests only were considered. The relationship between the prescribing of antidepressants and the effect modification model of forest proximity (1991-2001) was significantly different for all population groups tested (sex $p<0.001$; highest-level education $p<0.001$; Carstairs deprivation index $p<0.05$, urban rural classification $p<0.05$).

Lastly, for cohort 3, the association between each of the selected life course models and both mental health outcomes varied significantly by highest-level education (all forests and accessible forests only: prescribed antidepressants $p<0.01$; mental health outpatient $p<0.05$). The relationship between the accumulations of forest proximity on being a mental health outpatient also significantly varied by Carstairs deprivation index (all forests $p<0.05$; accessible forests only $p<0.05$). There were also significant interactions by sex for the prescribing of antidepressants (all forests $p<0.001$; accessible forests $p<0.001$) and being a mental health outpatient (all forests $p<0.05$).

Cohort	All forests: Prescribed antidepressants 2011-2016	All forests: Mental health outpatient 2011-2016	Accessible forests only: Prescribed antidepressants 2011-2016	Accessible forests only: Mental health outpatient 2011-2016
1	**Critical time period 2001**	**Critical time period 2011**	**Critical time period 2011**	**Critical time period 2011**
	Sex**	Sex	Sex**	Sex
	Highest-level education **	Highest-level education	Highest-level education **	Highest-level education
	Carstairs deprivation index (quintiles)**	Carstairs deprivation index (quintiles)	Carstairs deprivation index (quintiles)	Carstairs deprivation index (quintiles)
	Urban rural classification (2-fold)*	Urban rural classification (2-fold)	Urban rural classification (2-fold)	Urban rural classification (2-fold)
2	**Effect modification 1991-2001**	**Accumulation (strict)**	**None selected**	**Accumulation (strict)**
	Sex**	Sex		Sex
	Highest-level education **	Highest-level education **		Highest-level education **
	Carstairs deprivation index (quintiles)*	Carstairs deprivation index (quintiles)**		Carstairs deprivation index (quintiles)**
	Urban rural classification (2-fold)*	Urban rural classification (2-fold)		Urban rural classification (2-fold)
3	**Accumulation (strict)**	**Accumulation (strict)**	**Critical time period 2001**	**Accumulation (strict)**
	Sex**	Sex*	Sex**	Sex
	Highest-level education**	Highest-level education*	Highest-level education**	Highest-level education*
	Carstairs deprivation index (quintiles)	Carstairs deprivation index (quintiles)*	Carstairs deprivation index (quintiles)	Carstairs deprivation index (quintiles)*
	Urban rural classification (2-fold)	Urban rural classification (2-fold)	Urban rural classification (2-fold)	Urban rural classification (2-fold)

Table 6.9: Summary of Wald test results, testing the significance of interactions between population groups and life course models of forest proximity and mental health (** p<0.01, *p<0.05). Source: Scottish Longitudinal Study.

Significant interactions were then further explored using the 'margins' command in Stata. Fig.6.2-6.4 show the likelihood of having the mental health outcome of interest in each sociodemographic group, for each of the selected life course models of forest proximity.

Across the three cohorts, there were differences by sex, highest-level education and area-level deprivation in the relationships between life course models of forest proximity and the mental health outcomes explored. Throughout this section of analysis, the risk of having mental health issues was highest for women, those with no qualifications or living in the most deprived areas. However, there were key examples which illustrate potential implications of forest proximity for reducing such inequalities in mental health, which will now be presented.

6.3.4.1 Sex

Fig. 6.2a shows the probabilities of being prescribed antidepressants in 2011-2016, for males and females at each forest distance bands aged 28-39, which was identified as a critical period for those in cohort 1 (aged 38-49 in 2011). The plot indicates that the likelihood of being prescribed antidepressants for males and females was significantly different across the forest distance bands, as confidence intervals are not overlapping. Although women were at higher risk than men at each distance band, those who lived >=750m in 2001, were slightly more likely to be prescribed antidepressants in 2011-2016 than those who lived closer to forests. Whereas for men, it was those who lived 300-<750m in 2001 who were most likely to be prescribed. Women in cohort 2 (aged 50-64 in 2011) who lived 0-<300m in 1991 and 2001 had the lowest risk of being prescribed antidepressants in 2011-2016 than women in any other group (Fig.6.3a). For men there was a similar pattern, with those who had the best proximity to forests in 1991 and 2001 having the lowest risk. Also, of note in this plot is that the data points for men and women are more clustered together at the furthest distance band and gradually disperse as forest proximity improves. For those who lived closest to forests in 1991 and 2001, the differences in prescribing of antidepressants in 2011-2016 between men and women were no longer significant. This could indicate that inequalities in men and women's mental health were smaller amongst those who lived closest to forests. Furthermore, in cohort 3 (aged 65+ in 2011), Fig. 6.4a & Fig. 6.4c indicate that the inequalities between men and women reduced as cumulative forest proximity improved (all forests), for both mental health outcomes. Similar results were also found for accessible forests as the difference in risk of having antidepressants in 2011-2016 between men and women was smaller among those living 0-<300m than those living further from accessible forests aged 55+ (Fig. 6.4f).

6.3.4.2 Highest-level education

For those in cohort 1, the differences in likelihood of being prescribed antidepressants in 2011-2016 by education, was only significant for those living furthest from forests aged 28-39 (critical period 2001), with those without qualifications at the highest risk and those with degree qualification at the lowest risk (Fig. 6.2b). The inequality between these groups in the prescribing of antidepressants was also narrowest for those who lived 0-<300m from the nearest forest aged 28-39. However, this was due to those in this distance band with non-degree and degree qualifications having greater likelihood of being prescribed antidepressants rather than those without qualifications benefiting from better proximity to forests more than those with degrees. Furthermore, when differences by education level were investigated for cohort 3 (aged 45+ in 1991), inequalities in the prescribing of antidepressants between those without qualifications and with non-degree qualifications were narrower amongst those who had better cumulative forest proximity (Fig. 6.4b). This effect was also found when investigating differences by education-level when this group were aged 55+ (critical period 2001) (Fig. 6.4g) whereby the inequalities in the prescribing of antidepressants in 2011-2016 were smallest among those who lived closest to accessible forests in 2001. A contrasting example from cohort 2 is shown in Fig.6.3e. This plot shows the interaction between cumulative forest distance score (all forests) and highest-level education where the outcome is being a mental health outpatient in 2011-2016 and the reference category is those without qualifications. Although differences were very small (<2%) the plot indicates that as cumulative distance score increased (total forest proximity over the study period worsened) the difference in the risk of being a mental health outpatient between those without qualifications and degrees reduced.

6.3.4.3 Area-level deprivation

Lastly, significant interactions by area-level deprivation were explored. Fig.6.3f shows that the difference in risk of being a mental health outpatient between the most deprived areas and least deprived areas (reference category) is the same across all scores of cumulative forest distance, for those in cohort 2, which suggests that over the study period, inequalities in general mental health between the most and least deprived might not have varied according to levels of forest proximity. Similar trends were found when examining the same cohort and outcome but with accessible forests only, and these trends were also shown for those in Cohort 3.

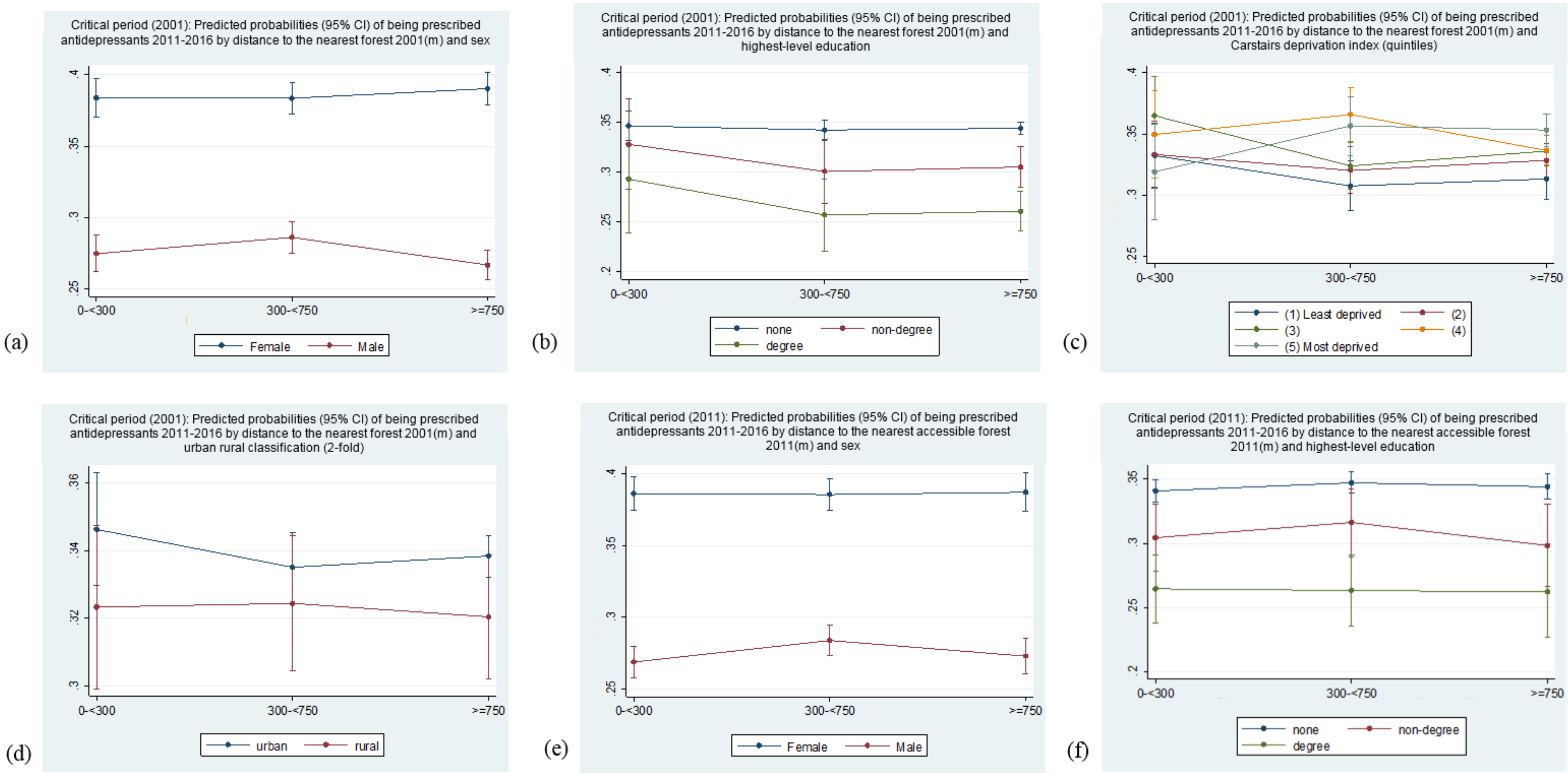


Fig. 6.2a-f: Adjusted interaction effects of life course models of forest access on mental health outcomes for Cohort 1, by sex, highest-level education and Carstairs deprivation index (quintiles). Models adjusted for: sex, children in the household, highest-level education, housing tenure, urban rural classification (2-fold) classification, distance to the coastline and whether or not the SLS member had the outcome previous to 2011. Source: Scottish Longitudinal Study.

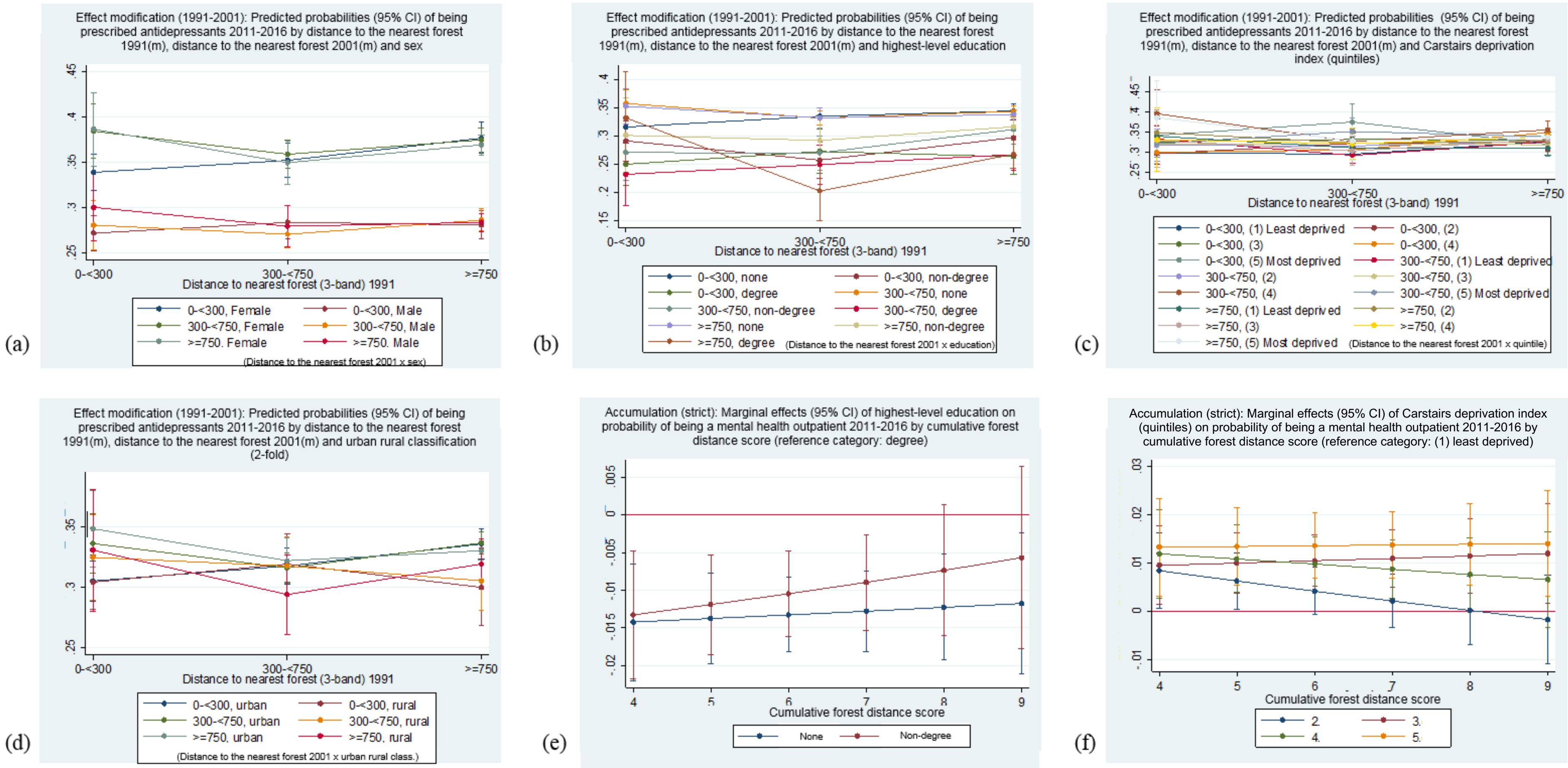
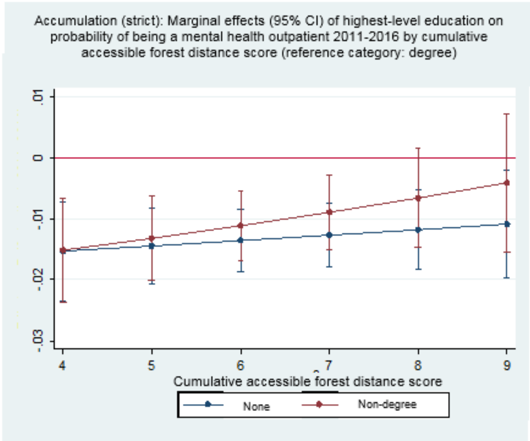


Fig. 6.3a-h: Adjusted interaction effects of life course models of forest access on mental health outcomes for Cohort 2, by sex, highest-level education, Carstairs deprivation index (quintiles) and urban rural (2-fold) classification. Models adjusted for: sex, children in the household, highest-level education, housing tenure, urban rural classification (2-fold), distance to the coastline and whether or not the SLS member had the outcome previous to 2011. Source: Scottish Longitudinal Study.

(g) 

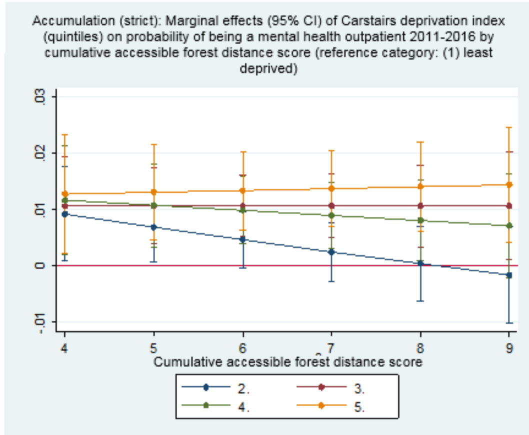
(h) 

Fig. 6.3a-h: continued.

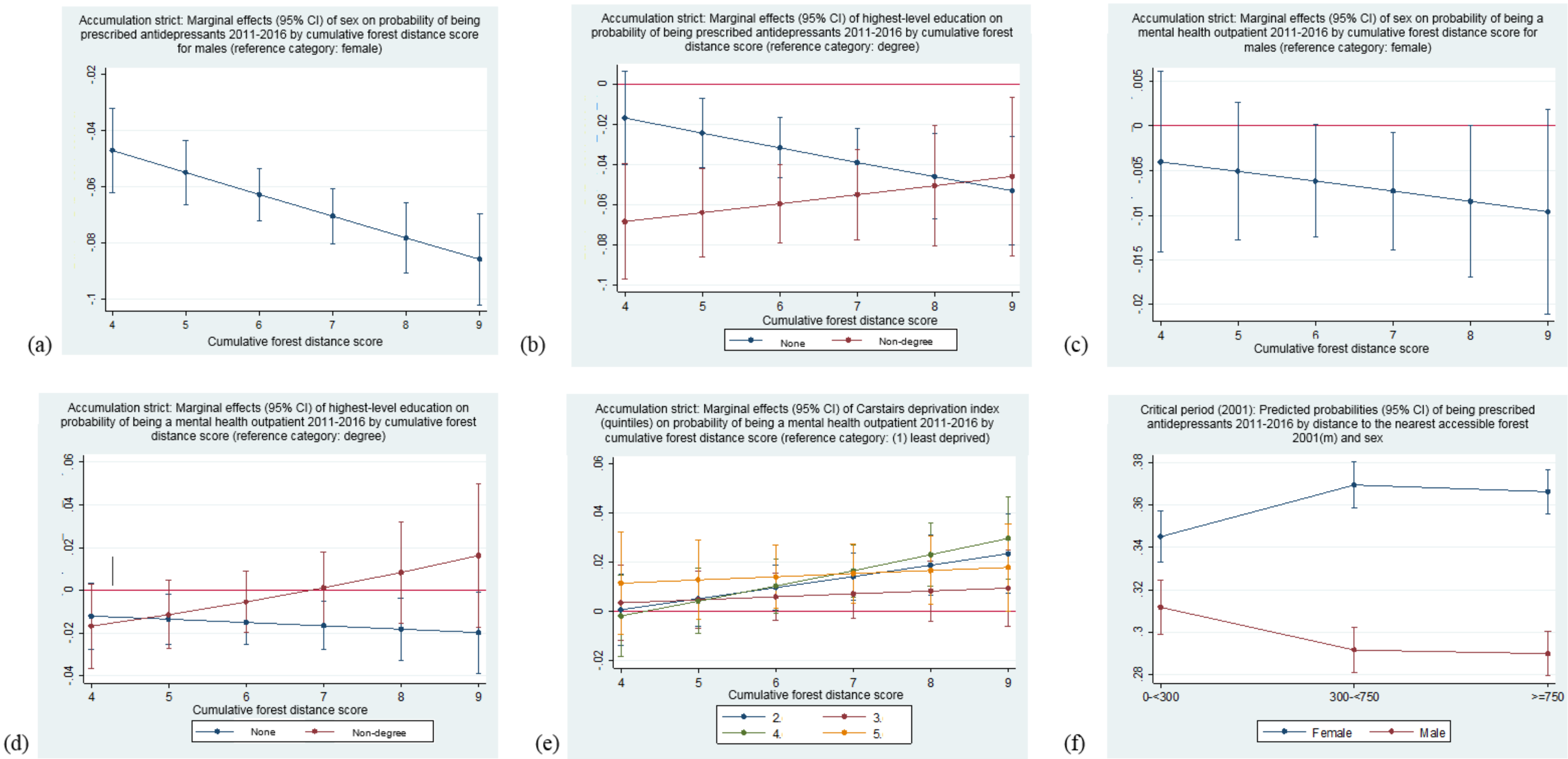
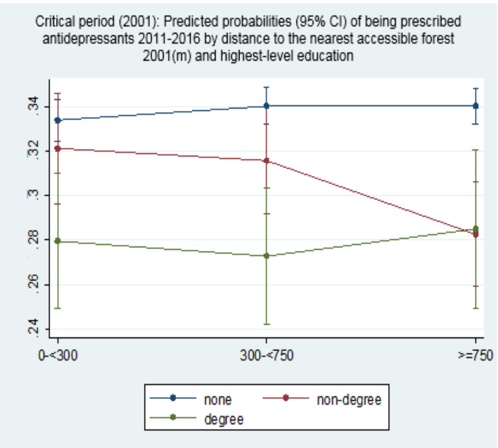


Fig. 6.4a-i: Adjusted interaction effects of life course models of forest access on mental health outcomes for Cohort 3, by sex, highest-level education and Carstairs deprivation index (quintiles). Models adjusted for: sex, children in the household, highest-level education, housing tenure, urban rural classification (2-fold), distance to the coastline and whether or not the SLS member had the outcome previous to 2011. Source: Scottish Longitudinal Study.

(g)



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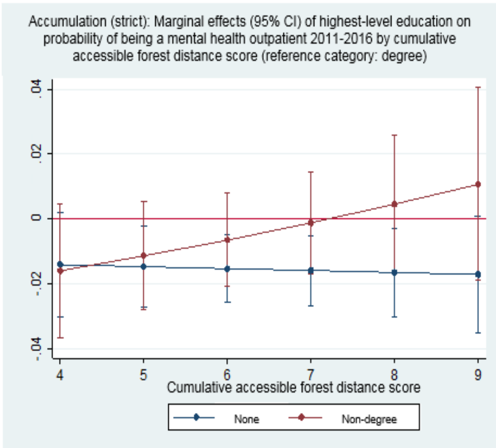


(i)

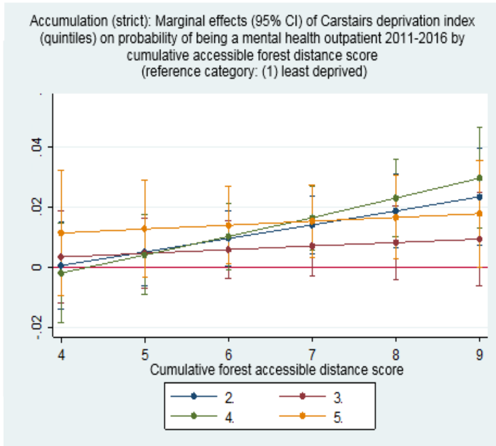


Fig. 6.4a-i: continued.

6.4 **Summary**

This chapter has applied a structured life course modelling framework in order to investigate how earlier levels of forest access may influence subsequent mental health. The relationship between forest access and mental health could not be adequately described by one life course model alone. Rather, selected life course models varied between the two different measures of mental health explored (prescribing of antidepressants and being a mental health outpatient), cohort and forest type. Many of these relationships were not statistically significant when demographic, socioeconomic and environmental factors were controlled for. However, for the few which remained significant, these indicated that for those who were middle-aged or older (cohort 3), the effect of having worse forest access accumulated over time and was associated with a higher risk of being a mental health outpatient twenty years later. Furthermore, although findings were not consistent across cohorts, some results suggested that forest access may only have protective effects on later mental health for certain groups; especially women. There was also indication that accumulation of better access to forests and better access at particular time points may have a role in reducing later inequalities in mental health between men and women and those of lower and higher socioeconomic status.

The main findings above are discussed alongside the chapter's methodological approach in Chapter 8. However, one key limitation was that the administrative mental health data used were only available towards the end of the study period, therefore associations between forests and mental health throughout the study period could not be explored. The next chapter provides insight to such associations by exploring whether changes in people's forest access were related to changes in general health, as reported in the 1991, 2001 and 2011 censuses. Also, by applying a synthetic measure of forest use, the chapter examines if people's use of forests explained associations between forest access and health.

7 Associations between changes in forest access and changes in general health

7.1 Introduction

The previous chapter explored the relationship between forests and different aspects of mental health over time, using life course models of health. It was found that for those aged 45 or older in 1991, the effect of worse forest access accumulated over time and was associated with increased risk of being a mental health outpatient at the end of the study period (2011-2016). For those aged 30-44 in 1991, results suggested that this particular life stage was a critical period at which forest access was particularly important for predicting prescribing of antidepressants in 2011-2016. Due to administrative health data not being available for all three time points, it was not possible to assess whether changes in people's health throughout the study period were linked to changes in forest access. This is an important step in establishing whether there is a causal relationship between forest access and health. This chapter attempts to address this issue by exploring whether people's likelihood of long-term illness (as reported in the census) reduced as forest access improved. Also, in order to further assess potential implications of forest access for health inequalities, this chapter examines the relationship for particular socio-demographic groups. Then, by utilising synthetic estimates of forest use, the Chapter investigates whether associations between forest access and health can be explained by people's use of forests, providing potential insight into the mechanisms through which forests may be related to health. The specific aim and research questions asked in this Chapter are:

To investigate whether changes in forest access over time are associated with changes in general health

- Are changes in individuals' forest access between 1991, 2001 and 2011 associated with changes in general health between time points?

- Does the above association vary between different socio-demographic groups (sex, socioeconomic status, age, area-level deprivation and urban rural classification)?
- Does use of forests explain the association between forest access and general health?

The chapter consists of two main sections. Firstly, the data transformation and statistical techniques applied in order to investigate the above questions are described. Then the results of the analyses are presented.

7.2 **Analysis plan**

7.2.1 Data transformation

For this set of analyses, the data set was transformed to 'long' format. This meant that there were multiple records per SLS member for each variable, and a categorical 'time' variable created to indicate the time point for each record. This allowed changes in people's forest access and changes in their health between time points to be investigated.

7.2.2 Exploring change using panel regression models

Panel regression models are used to explore associations in longitudinal data where observations at different time points are nested within individual people. These models are superior to standard regression methods as they take into consideration the multiple records per individual case in the data set and control for the effects of omitted variable bias i.e. the detailed aspects of life which are not measured in the data but which could be important predictors (Gayle & Lambert 2018). The fixed effects model and random effects model are two appropriate panel regression models for analysing change over time and have been used in previous studies to examine links between changes in access to green spaces, and changes in health outcomes. Examples include birth weight (Richardson et al. 2018) and mental health as measured by General Health Questionnaire (GHQ) score (van den Bosch et al. 2015; White et al. 2013b).

Fixed effects models focus on the variance within individuals and remove the effects of time-invariant predictors whether or not these are measured (Firebaugh et al. 2013). This means that regression coefficients represent change in a person's observations rather than the differences between individuals. On the other hand, random effects models consider both the between-person and within-person changes over time. Unlike the fixed effects models, random effects models can include predictors which can change over time e.g. housing tenure and age, or which are time-constant e.g. ethnicity and sex. However, one disadvantage, in comparison to the fixed effects model, is that random effects models do not automatically control for unobserved differences between individuals (Schempf & Kaufman 2017). Also, as the coefficients produced by the random-effects model are a combination of between and within effects, it is not entirely clear what the coefficients represent.

An alternative approach is to fit a hybrid model, which combines the advantages of the fixed and random effects models (Allison 2009). This involves fitting a single random effects model with two separate components: a between-person component (the person-specific mean of each variable) and a within-person component (deviation from the person-specific mean). This approach allows changes within individuals to be explored while effectively controlling for the between-person variation (Bell & Jones 2015). Therefore, it can be assessed whether changes in an individual's health over time is due to changes in their forest access or whether there are fundamental differences between those who change and do not change forest access, which are not accounted for in the model. The hybrid method is therefore more useful for identifying a significant causal relationship between forests and health than the fixed effects or random effects approaches on their own, as demonstrated in previous studies. Examples include an investigation into whether household moves were causally related to whether or not young people used cannabis (Morris et al. 2016) and whether changes in area-level socioeconomic status and alcohol outlet density were related to changes in weekly alcohol consumption (Brenner et al. 2015).

In this chapter, the measure of general health used is derived from the census and indicated whether or not the SLS member had a long-term illness. It is the only health measure included in all of the 1991, 2001 and 2011 censuses. Binary logistic random effects models were conducted first. These adjusted for robust standard errors and included a random intercept only. The log likelihood ratio test indicated that the model fit was better without including a random slope. The models examined the potential influence of forests and health over time, taking into account both the changes within individuals and variation between individuals. Secondly, hybrid effects models were used to deconstruct the 'within' and 'between' elements of the relationship. The model specifications for the random and hybrid effects models are shown in Fig. 7.1. The reference category for each of the forest proximity variables: (1) distance from home to the nearest forest and (2) distance from home to the nearest accessible forest was '>=1500m' as this had the largest number of observations. Models were also adjusted for age group, sex, ethnicity, children in the household, highest-level education, housing tenure, urban rural classification (2-fold) and distance from home to the coastline (km). Also, as identified in Chapters 5, forest access improved over the study period whilst the prevalence of illness increased due to the sample ageing. As argued by Wooldridge (2014), it was therefore important to control for this time effect in addition to age, where time was a categorical variable (1=1991, 2=2001, 3=2011). Covariates were added in the same three modelling steps used in Chapter 5 and Chapter 6.

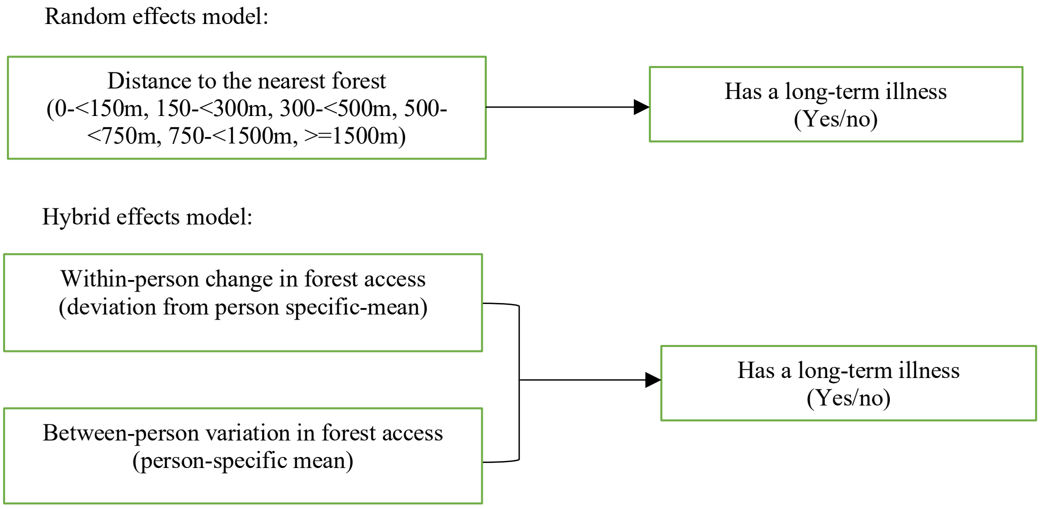


Fig. 7.1: Specifications for random effects and hybrid effects models, exploring changes in forest proximity and changes in general health. The between-person component is the person-specific mean across the three time points and the within-person component represents the deviation from the person-specific mean at each time point.

7.2.2.1 Differences by social groups

In order to investigate differences in the associations between forest and health by socio-demographic groups and across areas, the fully adjusted random effects and hybrid effects models were stratified by age group, sex, highest-level education, Carstairs deprivation index and urban-rural (2-fold) classification. The significance of the interactions between forest proximity and social groupings were examined using the Wald test. Significant interactions ($p<0.05$) were then further explored using the 'margins' command in Stata, as in Chapter 6.

7.2.3 Testing whether people's use of forests explained the association between forest access and general health

This part of the analysis utilised the synthetic estimates of forest use, specific to individual's age, ethnicity and housing tenure, as described in Chapter 3. These were linked to the SLS members and indicated the likelihood of visiting forests at least weekly, monthly and annually, at each time point. Using each of these indicators, mediation analyses showed whether use of forests (or visiting forests) explained the association between forest proximity and general health. In order to make use of data available at all time points, random effects models were conducted as in the previous section. A mediation analysis was conducted to test whether forest use explained the association between forest proximity and health. As described in Chapter 2, this approach has been adopted in previous studies exploring pathways between natural environments and health.

Following the approach applied in Lachowycz & Jones (2014), Dadvand et al. (2016) and Zijlema et al. (2017) to explore pathways between natural environments and health, the mediation analysis was conducted using a three-model framework (Baron & Kenny 1986). Fig. 7.2 illustrates the causal links tested, where path A is the influence of forest proximity on forest use; paths A and B represent the mediating role of forest use in the relationship between forest proximity and health; and path C is the direct influence of proximity to forests on health. As described in Chapter 2, there are four key pathways through which forests may be related to health. These are air quality, physical activity, social interaction and mental health (attention restoration and stress reduction). As demonstrated by Hartig et al. (2014), each of these pathways can influence health through forest use whereas two (enhanced air quality and mental health) can deliver health benefits without forest use. Therefore, it could be assumed that the direct pathway of good forest proximity on illness is through reducing air pollution and enhanced mental health; and the indirect effect could be enabling people to visit forests which may then provide opportunities for all four of the suggested pathways.

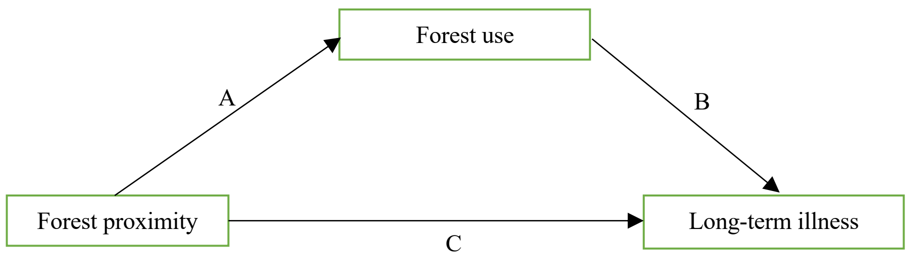


Fig. 7.2: Diagram showing the direct pathway (C) and the potential mediating role of forest use (A & B) in the relationship between proximity to forests and health.

In order for mediation to occur (with forest use as the mediator), three conditions must be satisfied. In Model 1, proximity to forests must be significantly associated with forest use (A). In Model 2, proximity to forests must be significantly associated with health (C); and in Model 3, when proximity to forests and forest use are both in the model, the size of the estimate for proximity to forests is smaller than in the second model (A & B). This would indicate that visiting forests is partially mediating the relationship. However, if in Model 3 proximity to forests is no longer significantly affecting health, this would be evidence of complete mediation (Kenny 2016). The analysis was conducted using each of the forest proximity measures (distance to the nearest forest; and distance to the nearest accessible forest) and each of the forest use estimates (visits at least weekly/monthly/annually).

7.3 **Results**

7.3.1 Did people's health improve when forest access improved?

Firstly, random effects models which examined the relationship between forest proximity and long-term illness, were conducted. The fully adjusted models (Table 7.1) showed that those who improved forest proximity between 1991-2001 and 2001-2011 were 16% less likely to have a long-term illness than when living furthest from forests (OR=0.84, 95% CI=0.87-0.90). When only taking into account forests which are accessible to the public, those living 0-<150m and 150-<300m were also significantly less likely to have a long-term illness (0-<150m OR=0.83, 95% CI=0.77-0.89; 150-<300m OR=0.92, 95% CI=0.86-0.98). However, as highlighted in section 7.2.2. the estimates produced by random-effects models are difficult to interpret as they represent a combination of between-person and within-person change.

The hybrid effects models were used to deconstruct the 'within' and 'between' components of the relationship between forest access and health. When both components were added to the model (Table 7.1), the between-person change was significant (OR=1.08, 95% CI=1.06-1.11) whilst the within-person change was insignificant (OR=1.00, 95% CI=0.99-1.02). These results indicate that (a) an individual for whom forest distance increased between time points (from their mean forest distance), either by moving to an area with worse forest proximity or by their nearest forest being felled, were 8% more likely to have a long term illness than an individual who did not change level of forest proximity between the three time points; and (b) there was no difference in the chance of having a long-term illness when an individual changed forest proximity between time points compared to when the same individual did not change forest proximity between time points. Therefore, people were not healthier when they lived closer to forests. Instead, the significant effects seen in the random effects' models were due to unobserved differences between those with improved forest proximity and those who remained living >=1500m from the nearest forest. Findings were almost identical when only the accessible forests were considered (within-person component OR=1.01, 95% CI=0.99-1.02; between-person component OR=1.08, 95% CI=1.06-1.10).

	All forests		**Accessible forests only**	
	Random effects	**Hybrid effects**	**Random effects**	**Hybrid effects**
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
Within-person component*		1.00 (0.99-1.02)		1.01 (0.99-1.02)
Between-person component*		**1.08** (1.06-1.11)		**1.08** (1.06-1.10)
Distance to the nearest forest (m)				
0-<150	**0.84** (0.78-0.90)		**0.83** (0.77-0.89)	
150-<300	0.93 (0.87-1.00)		**0.92** (0.86-0.98)	
300-<500	0.97 (0.91-1.04)		0.95 (0.90-1.02)	
500-<750	0.99 (0.93-1.06)		0.98 (0.92-1.04)	
750-<1500	0.99 (0.93-1.05)		0.99 (0.93-1.05)	

Table 7.1: Random effects and hybrid effects models, exploring the association between forest proximity and long-term illness, adjusted for time, age group, sex, ethnicity, children in the household, highest-level educational qualification, housing tenure, urban rural classification (2-fold) and distance to the coastline (km). OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.
*Odds ratios for within and between person components are for the categorical variable, Distance to the nearest forest (m), treated as a linear predictor.

7.3.1.1 Differences between demographic groups and geographical areas

The fully adjusted random effects and hybrid effects models were stratified by age, sex, highest-level educational qualification, Carstairs deprivation index (quintiles) and urban-rural classification (2-fold). Notably, when all forests were considered (Table 7.2), reducing distance from home to the nearest forest from >=1500m to distance bands within 500m was associated with reduced odds of long-term illness for those without qualifications only (e.g. 0-<150m OR=0.79, 95% CI=0.72-0.87). Results were very similar when examining accessible forests only (Table 7.3).

Differences between males and females were also identified. Whereas improving forest proximity from living >=1500m from the nearest forest to within 0-<150m, was beneficial for both men and women, men were also significantly less likely to have a long-term illness when living within 500m to the nearest forest (e.g. 300-<500m OR=0.90, 95% CI=0.82-1.00). Males also benefited from living near accessible forests, more so than females. Compared to men living furthest from forests, those who improved forest proximity had significantly reduced odds of long-term illness, for all distance bands (e.g. 0-<150m OR=0.79, 95% CI=0.72-0.88).

Some differences were found between age groups, urban and rural areas and by area-level deprivation. For example, those aged 18-29 in 1991 were the only age group not to have reduced odds of long-term illness when living 0-<150m to the nearest forest (both forest types), compared to living >=1500m; and only those in urban areas benefited from living within 150m of the nearest forest (OR=0.84, 95% CI=0.78-0.92).

Also shown in Table 7.3, when the hybrid model was stratified, within-person changes in distance to the nearest forest (taking into account all forests) was not significantly associated with changes in health for any group. The between-person component was significant for all groups, except for those in the least deprived and second least deprived areas. This suggests that for these areas, there was no difference in health status between those who experienced changes in forest proximity during the study period, and those who did not change levels of forest proximity. When only the accessible forests were considered, changes in forest proximity within the same individuals were only significantly associated with changes in health for those aged 30-44 in 1991 (OR=1.03, 95% CI=1.00-1.05). This means that for this group only, as distance to the nearest accessible forests increases by one distance band (from the person's mean forest distance band), likelihood of long-term illness increased by 3%. For all other groups, results suggest that the variances found in the random effects models were due to unobserved differences between individuals rather than due to within-person change.

	Random effects model					Hybrid effects model	
	0-<150 OR (95% CI)	150-<300 OR (95% CI)	300-<500 OR (95% CI)	500-<750 OR (95% CI)	750-<1500 OR (95% CI)	Within-person OR (95% CI)	Between-person OR (95% CI)
Sex							
Females	**0.86** (0.78-0.95)	0.98 (0.89-1.07)	1.03 (0.94-1.12)	1.06 (0.97-1.16)	1.06 (0.98-1.15)	1.01 (0.99-1.03)	**1.08** (1.05-1.11)
Males	**0.81** (0.73-0.90)	**0.88** (0.79-0.98)	**0.90** (0.82-1.00)	0.92 (0.83-1.01)	**0.91** (0.83-1.00)	0.99 (0.97-1.01)	**1.09** (1.06-1.12)
Highest-level education							
No qualifications	**0.79** (0.72-0.87)	**0.90** (0.82-0.98)	**0.88** (0.81-0.96)	0.93 (0.86-1.01)	**0.93** (0.87-1.00)	1.01 (0.99-1.03)	**1.07** (1.05-1.10)
Non-degree	0.96 (0.82-1.13)	1.08 (0.92-1.26)	1.13 (0.97-1.32)	1.15 (0.99-1.35)	**1.19** (1.03-1.38)	0.99 (0.96-1.02)	**1.08** (1.05-1.12)
Degree	0.86 (0.69-1.07)	0.90 (0.73-1.12)	1.09 (0.88-1.36)	1.06 (0.85-1.31)	0.99 (0.81-1.22)	0.97 (0.93-1.01)	**1.12** (1.07-1.17)
Carstairs deprivation index (quintiles)							
1 (least deprived)	0.98 (0.81-1.19)	1.00 (0.83-1.21)	1.03 (0.85-1.24)	1.12 (0.92-1.35)	1.04 (0.87-1.25)	1.02 (0.98-1.06)	1.01 (0.98-1.05)
2	1.01 (0.85-1.20)	1.13 (0.95-1.34)	1.13 (0.95-1.33)	1.09 (0.92-1.28)	1.10 (0.94-1.29)	0.97 (0.94-1.01)	1.03 (0.99-1.07)
3	0.90 (0.77-1.07)	0.98 (0.83-1.15)	1.06 (0.91-1.23)	0.98 (0.84-1.14)	1.00 (0.87-1.15)	0.97 (0.93-1.01)	**1.06** (1.02-1.10)
4	**0.80** (0.68-0.94)	0.92 (0.79-1.07)	**0.86** (0.75-0.99)	0.91 (0.79-1.05)	0.89 (0.78-1.01)	1.01 (0.97-1.05)	**1.04** (1.00-1.08)
5 (most deprived)	0.92 (0.77-1.09)	0.99 (0.85-1.16)	1.07 (0.93-1.23)	**1.14** (1.00-1.31)	1.07 (0.95-1.21)	1.00 (0.97-1.04)	**1.04** (1.00-1.08)
Urban rural classification (2-fold)							
Urban	**0.84** (0.78-0.92)	0.93 (0.86-1.01)	0.93 (0.86-1.01)	1.00 (0.93-1.07)	0.99 (0.92-1.05)	1.00 (0.98-1.01)	**1.08** (1.06-1.10)
Rural	0.86 (0.70-1.06)	1.02 (0.82-1.25)	0.97 (0.79-1.19)	1.06 (0.86-1.31)	1.08 (0.88-1.31)	1.01 (0.97-1.05)	**1.08** (1.03-1.12)
Age group 1991							
18-29	0.88 (0.75-1.05)	0.96 (0.82-1.13)	1.03 (0.89-1.20)	1.07 (0.92-1.24)	1.02 (0.89-1.18)	0.99 (0.96-1.03)	**1.09** (1.04-1.14)
30-44	**0.83** (0.73-0.94)	1.02 (0.90-1.15)	0.99 (0.88-1.11)	1.04 (0.93-1.17)	1.07 (0.97-1.20)	1.01 (0.98-1.04)	**1.09** (1.05-1.13)
45-54	**0.84** (0.72-0.98)	**0.84** (0.73-0.97)	0.91 (0.79-1.05)	0.93 (0.82-1.07)	0.95 (0.84-1.07)	0.99 (0.96-1.02)	**1.11** (1.07-1.16)
55+	**0.84** (0.72-0.98)	0.89 (0.77-1.03)	0.95 (0.83-1.09)	0.95 (0.83-1.09)	0.92 (0.81-1.03)	1.00 (0.96-1.03)	**1.06** (1.02-1.10)

Table 7.2: Random-effects and hybrid effects models exploring associations between forest proximity (all forests) and long-term illness, stratified by demographic and socioeconomic groups. Models adjusted for: time, age group, sex, ethnicity, children in the household, highest-level education, housing tenure, urban rural classification (2-fold) and distance from the coastline. OR significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

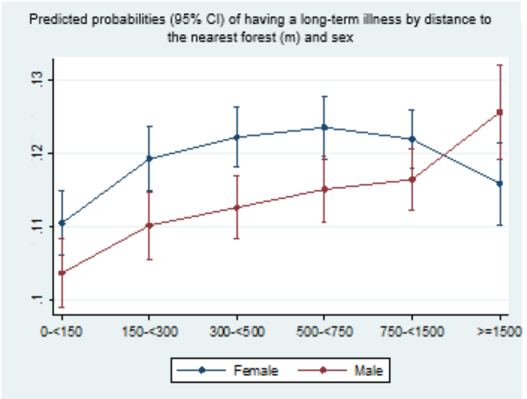
	Random effects model					Hybrid effects model	
	0-<150 **OR (95% CI)**	**150-<300** **OR (95% CI)**	**300-<500** **OR (95% CI)**	**500-<750** **OR (95% CI)**	**750-<1500** **OR (95% CI)**	**Within-person** **OR (95% CI)**	**Between-person** **OR (95% CI)**
Sex							
Females	**0.86** (0.78-0.95)	0.96 (0.88-1.06)	1.02 (0.94-1.11)	1.05 (0.97-1.14)	1.06 (0.98-1.14)	1.01 (0.99-1.03)	**1.07** (1.05-1.10)
Males	**0.79** (0.72-0.88)	**0.87** (0.78-0.96)	**0.88** (0.80-0.96)	**0.89** (0.81-0.98)	**0.91** (0.84-0.99)	1.00 (0.98-1.02)	**1.09** (1.06-1.12)
Highest-level education							
No qualifications	**0.80** (0.73-0.88)	**0.90** (0.82-0.98)	**0.88** (0.81-0.95)	0.93 (0.86-1.00)	0.94 (0.88-1.01)	1.01 (0.99-1.03)	**1.07** (1.05-1.10)
Non-degree	0.93 (0.81-1.08)	1.03 (0.89-1.19)	1.11 (0.97-1.28)	1.09 (0.95-1.26)	**1.16** (1.02-1.33)	0.99 (0.96-1.03)	**1.07** (1.04-1.11)
Degree	**0.77** (0.63-0.94)	0.83 (0.68-1.01)	0.98 (0.81-1.19)	0.97 (0.80-1.18)	0.93 (0.78-1.12)	0.99 (0.95-1.03)	**1.12** (1.07-1.17)
Carstairs deprivation index (quintiles)							
1 (least deprived)	0.96 (0.80-1.13)	0.94 (0.79-1.12)	0.99 (0.83-1.17)	1.01 (0.85-1.20)	1.06 (0.91-1.25)	1.03 (0.99-1.06)	1.02 (0.98-1.06)
2	1.03 (0.88-1.21)	1.13 (0.96-1.32)	1.13 (0.96-1.32)	**1.17** (1.00-1.37)	1.15 (0.99-1.32)	0.98 (0.94-1.01)	1.03 (1.00-1.07)
3	0.86 (0.74-1.01)	0.95 (0.82-1.11)	1.04 (0.90-1.19)	0.94 (0.82-1.09)	0.97 (0.85-1.10)	0.97 (0.94-1.01)	**1.06** (1.02-1.10)
4	**0.81** (0.69-0.96)	0.96 (0.83-1.11)	0.92 (0.81-1.06)	0.93 (0.81-1.07)	0.93 (0.81-1.07)	1.00 (0.97-1.04)	**1.04** (1.00-1.08)
5 (most deprived)	0.89 (0.75-1.06)	0.94 (0.81-1.09)	1.01 (0.88-1.15)	1.07 (0.94-1.22)	1.01 (0.90-1.13)	1.01 (0.97-1.05)	**1.03** (0.99-1.07)
Urban rural classification (2-fold)							
Urban	**0.84** (0.78-0.91)	**0.93** (0.86-1.00)	0.97 (0.91-1.04)	0.99 (0.92-1.06)	0.98 (0.92-1.04)	1.00 (0.98-1.02)	**1.08** (1.05-1.10)
Rural	**0.80** (0.67-0.96)	0.92 (0.76-1.10)	0.90 (0.75-1.07)	0.96 (0.80-1.15)	1.06 (0.90-1.25)	1.03 (0.99-1.07)	**1.09** (1.04-1.13)
Age group 1991							
18-29	0.91 (0.78-1.07)	0.96 (0.82-1.12)	1.01 (0.87-1.17)	1.08 (0.94-1.25)	0.99 (0.87-1.12)	0.99 (0.96-1.02)	1.08 (1.03-1.12)
30-44	**0.78** (0.69-0.88)	0.94 (0.83-1.05)	0.92 (0.83-1.03)	0.98 (0.88-1.09)	1.02 (0.93-1.13)	**1.03** (1.00-1.05)	**1.09** (1.05-1.12)
45-54	**0.85** (0.73-0.98)	**0.86** (0.75-0.99)	0.91 (0.80-1.04)	0.91 (0.80-1.04)	0.96 (0.85-1.08)	0.98 (0.95-1.01)	**1.12** (1.08-1.16)
55+	**0.85** (0.73-0.98)	0.92 (0.80-1.06)	1.00 (0.88-1.14)	0.98 (0.87-1.12)	0.98 (0.88-1.10)	1.01 (0.97-1.04)	**1.05** (1.01-1.09)

Table 7.3: Random effects and hybrid effects models exploring associations between forest proximity (accessible forests only) and long-term illness, stratified by demographic and socioeconomic groups. Models adjusted for: time, age group, sex, ethnicity, children in the household, highest-level education, housing tenure, urban rural classification (2-fold) and distance from the coastline. OR significant $p<0.05$ shown in boldface. Source: Scottish Longitudinal Study.

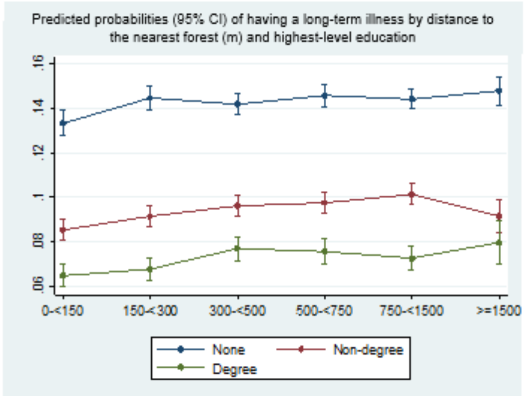
The interactions between forest proximity and social groupings were then explored. The results of Wald Tests showed that the relationship between forest proximity (all forests and accessible forests only) and long-term illness varied significantly between males and females ($p<0.01$), those with different levels of educational achievement ($p<0.05$) and age groups ($p<0.0001$). Significant interactions were then further explored using the 'margins' command in Stata. This technique allows investigation into whether inequalities in health vary between different levels of forest proximity. Fig.7.3a-3f show the probabilities of having long-term illness for each of the sexes, age groups and education levels, at each forest distance category. The plots indicated that inequalities in long-term illness between these socio-demographic groups were not lower for those with better access to forests. This is perhaps surprising given that previous studies have shown narrower socioeconomic health inequalities in areas with more green space (Mitchell et al. 2015; Mitchell & Popham 2008).

To summarise thus far, the findings suggest that for the whole sample, people's health did not improve when their level of forest proximity improved between the time points. However, those individuals who had improved proximity to forests tended to have better health than those individuals who did not change forest proximity, for reasons unaccounted for in the models. The beneficial effect of forests on illness was particularly stark for males and those without qualifications. However, exploring interactions between forest proximity and education level provided no evidence that forest access reduced socioeconomic health inequalities, nor inequalities between males and females.

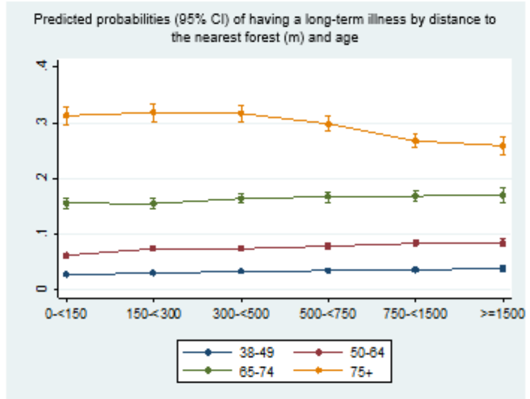
Overall, results suggest that the influence of forest access on general health is inconsistent across social groups. Potential explanations for these findings are discussed in the following chapter. Moving on, the next section of this Chapter investigates whether *use* of forests explains the association between forest access and general health.



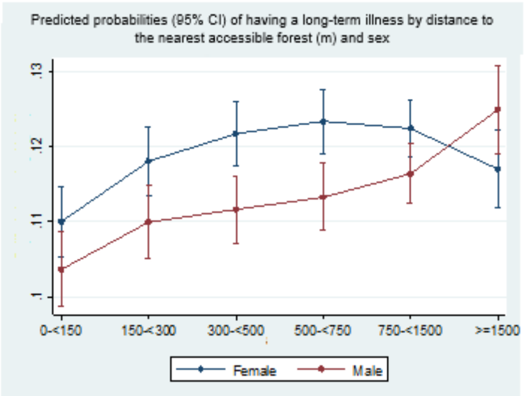
(a)



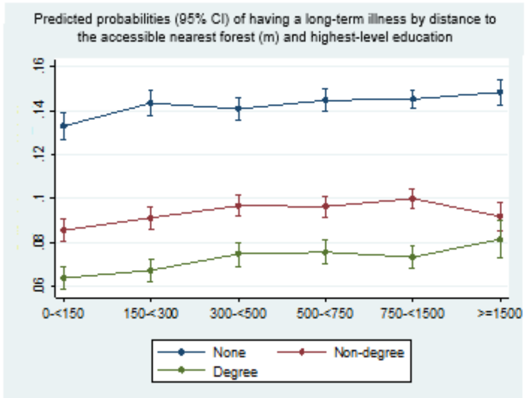
(c)



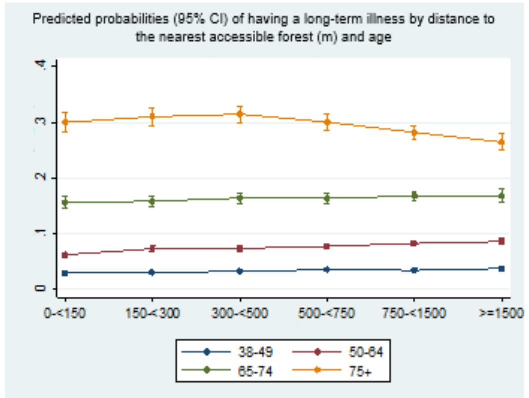
(e)



(b)



(d)



(f)

Fig.7.3a-3f: Adjusted interaction effects of distance from home to the nearest forest (m), on long-term illness by age group, sex and highest-level education. Models adjusted for: time, age group, sex, ethnicity, children in the household, highest-level education, housing tenure, urban rural classification (2-fold) and distance from the coastline. Source: Scottish Longitudinal Study.

7.3.2 Were people who lived nearer to forests healthier because they visited them?

A measure of forest use was calculated. As explained in Chapter 3, synthetic estimates were created for visiting forests at least weekly, monthly and annually and linked to the SLS members. These were used in a mediation analysis to determine the extent to which associations between forests and health were due to people's use of forests. The analysis followed the 3-model framework proposed by Baron & Kenny (1986). This was conducted for all forests and only those forests which are accessible to the public.

Firstly, the relationship between forest proximity and forest use was tested. Findings showed that compared to living >=1500m from the nearest forest, people living in distance bands closer to forests were significantly more likely to visit them, for visiting at least weekly (Table 7.4 & 7.5), monthly (Table 7.6 & 7.7) and annually (Table 7.8 & 7.9). There was a clear trend as likelihood of visiting forests increased as distance to the nearest forest decreased. Probability of visiting forests at least monthly increased by 0.51, from those living >=1500m to those living 0-<150m from the nearest forest (β=0.51, 95% CI=0.43-0.60); and 0.46 for those living 150-<300m (β=0.46, 95% CI=0.38-0.54). Restricting the analysis to accessible forests only produced similar results however estimate sizes were slightly smaller.

The results of Model 2, which assessed the direct relationship between forest proximity and health, indicated that those living 0-<500m from the nearest forest were significantly less likely to have a long-term illness, than those living >=1500m (e.g. 0-<150m OR=0.73, 95% CI=0.67-0.79). Again, findings were similar for when only accessible forests were considered.

Lastly, both forest proximity and forest use were modelled with long-term illness to test whether use of forests mediates the relationship between forest proximity and health. When the probability of visiting forests at least monthly was added, the effect of forest proximity on health reduced in size and remained significant for those living 0-<150m and 150-<300m from the nearest forest. For those living 0-<150m of the nearest forest, the likelihood of having a long-term illness decreased from 27% in Model 2 (OR=0.73, 95% CI=0.67-0.79) to 23% in Model 3 (OR=0.77, 95% CI=0.72-0.83). These results suggest that visiting forests at least monthly partially mediates the relationship between forest proximity and having a long-term illness and that this effect is greater for those living closest to forests. Secondly, there may also still be a direct effect of forest access on health. People could potentially benefit from living within 300m of forests for example from better air quality, without visiting them.

Model 3 was adjusted by demographic, socioeconomic and environmental factors. The direct effect of forest proximity remained significant for people living 0-<150m from the nearest forest only (all forests considered), for all visit frequencies. However, when only publicly accessible forests were considered, the direct effect of living 0-<150m and 150-<300m from the nearest forest remained significant with those living 0-<150m having the greatest benefit (e.g. when testing the effect of visiting forests at least monthly: 0-<150m OR=0.83, 95% CI=0.77-0.89; 150-<300m OR=0.92, 95% CI=0.86-0.99). Therefore, when also considering potential confounders, the benefits of using forests may be restricted to those in immediate proximity of forests.

	Model 1: Probability of visiting forests at least weekly	Model 2: Has a long-term illness	Model 3: Has a long-term illness	
			Unadjusted	Adjusted
	β (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
Probability of visiting forests at least weekly			**0.76** (0.76-0.77)	**0.93** (0.92-0.94)
Distance to the nearest forest(m) (all forests)				
0-<150	**0.44 (**0.39-0.49)	**0.73** (0.67-0.79)	**0.80** (0.74-0.86)	**0.84 (**0.78-0.90)
150-<300	**0.36 (**0.31-0.41)	**0.87** (0.81-0.94)	**0.93** (0.87-1.00)	0.94 (0.87-1.01)
300-<500	**0.30 (**0.25-0.34)	**0.93 (**0.86-0.99)	0.98 (0.92-1.05)	0.97 (0.91-1.04)
500-<750	**0.29** (0.25-0.33)	0.96 (0.90-1.03)	1.02 (0.96-1.09)	1.00 (0.94-1.07)
750-<1500	**0.20 (**0.16-0.23)	0.98 (0.92-1.04)	1.02 (0.96-1.09)	1.00 (0.94-1.06)

Table 7.4: Mediation analysis results, indicating whether the probability of visiting forests at least weekly explains the association between forest proximity (all forests) and long-term illness. Adjusted model controls for time, age group, sex, ethnicity, children in the household, highest-level educational qualification, housing tenure, urban rural classification (2-fold) and distance to the coastline (km). OR/β significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

	Model 1: Probability of visiting forests at least weekly	Model 2: Has a long-term illness	Model 3: Has a long-term illness	
			Unadjusted	Adjusted
	β (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
Probability of visiting forests at least weekly			**0.76** (0.76-0.77)	**0.93** (0.92-0.94)
Distance to the nearest forest(m) (accessible forests only)				
0-<150	**0.39** (0.34-0.44)	**0.74** (0.69-0.79)	**0.80** (0.74-0.86)	**0.83 (**0.77-0.89)
150-<300	**0.32** (0.27-0.36)	**0.88** (0.82-0.94)	**0.93** (0.87-1.00)	**0.92** (0.86-0.99)
300-<500	**0.26** (0.21-0.30)	**0.93 (**0.87-1.00)	0.98 (0.92-1.04)	0.96 (0.90-1.02)
500-<750	**0.27** (0.23-0.31)	0.96 (0.90-1.02)	1.01 (0.95-1.08)	0.98 (0.92-1.05)
750-<1500	**0.17** (0.13-0.21)	0.99 (0.94-1.05)	1.03 (0.97-1.09)	0.99 (0.94-1.05)

Table 7.5: Mediation analysis results, indicating whether the probability of visiting forests at least weekly explains the association between forest proximity (accessible forests only) and long-term illness. Adjusted model controls for time, age group, sex, ethnicity, children in the household, highest-level educational qualification, housing tenure, urban rural classification (2-fold) and distance to the coastline (km). OR/β significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

	Model 1: Probability of visiting forests at least monthly	Model 2: Has a long-term illness	Model 3: Has a long-term illness	
			Unadjusted	Adjusted
	β (95%CI)	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI)**
Probability of visiting forests at least monthly			**0.86** (0.86-0.86)	**0.93** (0.92-0.94)
Distance to the nearest forest(m) (all forests)				
0-<150	**0.51** (0.43-0.60)	**0.73** (0.67-0.79)	**0.77** (0.72-0.83)	**0.84** (0.78-0.90)
150-<300	**0.46** (0.38-0.54)	**0.87** (0.81-0.94)	**0.92** (0.85-0.98)	0.94 (0.87-1.01)
300-<500	**0.41** (0.34-0.48)	**0.93** (0.86-0.99)	0.97 (0.90-1.03)	0.97 (0.91-1.04)
500-<750	**0.42** (0.35-0.49)	0.96 (0.90-1.03)	1.01 (0.95-1.08)	1.00 (0.94-1.07)
750-<1500	**0.32** (0.26-0.38)	0.98 (0.92-1.04)	1.02 (0.96-1.09)	1.00 (0.94-1.06)

Table 7.6: Mediation analysis results, indicating whether the probability of visiting forests at least monthly explains the association between forest proximity (all forests) and long-term illness. Adjusted model controls for time, age group, sex, ethnicity, children in the household, highest-level educational qualification, housing tenure, urban rural classification (2-fold) and distance to the coastline (km). OR/β significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

	Model 1: Probability of visiting forests at least monthly	Model 2: Has a long-term illness	Model 3: Has a long-term illness	
			Unadjusted	Adjusted
	β (95%CI)	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI)**
Probability of visiting forests at least monthly			**0.86** (0.86-0.86)	**0.95** (0.95-0.95)
Distance to the nearest forest(m) (accessible forests only)				
0-<150	**0.45** (0.36-0.53)	**0.74** (0.69-0.79)	**0.77** (0.72-0.83)	**0.83** (0.77-0.89)
150-<300	**0.41** (0.33-0.49)	**0.88** (0.82-0.94)	**0.92** (0.86-0.98)	**0.92** (0.86-0.99)
300-<500	**0.38** (0.31-0.45)	**0.93** (0.87-1.00)	0.97 (0.91-1.03)	0.96 (0.90-1.02)
500-<750	**0.40** (0.34-0.47)	0.96 (0.90-1.02)	1.01 (0.95-1.07)	0.98 (0.92-1.05)
750-<1500	**0.28** (0.23-0.34)	0.99 (0.94-1.05)	1.03 (0.98-1.09)	0.99 (0.94-1.05)

Table 7.7: Mediation analysis results, indicating whether the probability of visiting forests at least monthly explains the association between forest proximity (accessible forests only) and long-term illness. Adjusted model controls for time, age group, sex, ethnicity, children in the household, highest-level educational qualification, housing tenure, urban rural classification (2-fold) and distance to the coastline (km). OR/β significant *p<0.05* shown in boldface. Source: Scottish Longitudinal Study.

	Model 1: Probability of visiting forests at least annually	Model 2: Has a long-term illness	Model 3: Has a long-term illness	
			Unadjusted	**Adjusted**
	β (95%CI)	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI)**
Probability of visiting forests at least annually			**0.88** (0.88-0.88)	**0.97** (0.96-0.97)
Distance to the nearest forest(m) (all forests)				
0-<150	**0.61** (0.50-0.71)	**0.73** (0.67-0.79)	**0.77** (0.72-0.83)	**0.84** (0.78-0.90)
150-<300	**0.54** (0.44-0.63)	**0.87** (0.81-0.94)	**0.91** (0.85-0.98)	0.94 (0.87-1.01)
300-<500	**0.46** (0.37-0.55)	**0.93** (0.86-0.99)	0.96 (0.90-1.03)	0.97 (0.91-1.04)
500-<750	**0.47** (0.39-0.56)	0.96 (0.90-1.03)	1.01 (0.94-1.07)	1.00 (0.93-1.07)
750-<1500	**0.36** (0.28-0.43)	0.98 (0.92-1.04)	1.02 (0.96-1.08)	0.99 (0.94-1.06)

Table 7.8: Mediation analysis results, indicating whether the probability of visiting forests at least annually explains the association between forest proximity (all forests) and long-term illness. Adjusted model controls for time, age group, sex, ethnicity, children in the household, highest-level educational qualification, housing tenure, urban rural classification (2-fold) and distance to the coastline (km). Source: Scottish Longitudinal Study.

	Model 1: Probability of visiting forests at least annually	Model 2: Has a long-term illness	Model 3: Has a long-term illness	
			Unadjusted	**Adjusted**
	β (95%CI)	**OR (95%CI)**	**OR (95%CI)**	**OR (95%CI)**
Probability of visiting forests at least annually			**0.88** (0.88-0.88)	**0.97** (0.96-0.97)
Distance to the nearest forest(m) (accessible forests only)				
0-<150	**0.53** (0.43-0.64)	**0.74** (0.69-0.79)	**0.77** (0.72-0.83)	**0.83** (0.77-0.89)
150-<300	**0.47** (0.37-0.57)	**0.88** (0.82-0.94)	**0.91** (0.86-0.98)	**0.92** (0.86-0.99)
300-<500	**0.41** (0.32-0.50)	**0.93** (0.87-1.00)	0.97 (0.91-1.03)	0.96 (0.90-1.02)
500-<750	**0.46** (0.37-0.54)	0.96 (0.90-1.02)	1.00 (0.94-1.07)	0.98 (0.92-1.04)
750-<1500	**0.31** (0.24-0.38)	0.99 (0.94-1.05)	1.02 (0.97-1.08)	0.99 (0.94-1.05)

Table 7.9: Mediation analysis results, indicating whether the probability of visiting forests at least annually explains the association between forest proximity (accessible forests only) and long-term illness. Adjusted model controls for time, age group, sex, ethnicity, children in the household, highest-level educational qualification, housing tenure, urban rural classification (2-fold) and distance to the coastline (km). Source: Scottish Longitudinal Study.

7.4 **Summary**

This chapter used random effects and hybrid effects models to examine associations between changes in forest access and changes in people's health. It also investigated whether visiting forests explained the relationship between forests and general health by using synthetic estimates of forest use in mediation analyses. The results indicated that the associations between forests and reduced chance of illness identified were not due to people's forest access improving. Instead, the association found is more likely due to underlying differences between those whose access to forests improved and those whose access did not improve. It was also found that forest use partially mediated the relationship between forest access and health and that there still remained a direct effect of forest access and health for those living in immediate proximity to forests. Throughout the chapter, significant differences were found between demographic and socioeconomic groups: most notable was that forests were particularly beneficial to the general health of males and those without qualifications.

This was the first-time longitudinal data and analytical techniques have been applied to large secondary data sets in order to provide causal insights to the relationship between forests and health. This significant contribution to the wider literature, and that of the thesis as a whole will now be discussed in the following and final chapter.

8 Discussion and Conclusions

8.1 Introduction

Internationally, this was the first population-level study to investigate associations between forests, health and inequalities by applying a longitudinal approach. The thesis explored relationships between people's forest access and different health outcomes in Scotland over a 20-year period, within a framework of socio-ecological models and environmental justice. The main strengths of the thesis were the use of longitudinal data about people's forest access and health at three different time points and the linkage of administrative health records for a large, representative sample of individuals.

The main findings of the first sets of analysis were that, for the whole of Scotland, forest access improved over the study period. However, forest access was consistently worse in deprived areas across all three time points and individuals with low socioeconomic status at the start of the study period were likely to have worse forest access trajectories than those with higher socioeconomic status. These findings suggest there has been a continuing pattern of environmental injustice, particularly as those with better forest access trajectories were more likely to have good general and mental health at the end of the study period than those with worse forest access trajectories.

In Chapter 6 it was found that there might be protective effects of forests, for different aspects of health, for certain sociodemographic groups, most notably by sex and socioeconomic status. For women, those who had greater accumulation of forest access over the study period were found to be less likely to have mental health problems than those with lower levels of cumulative forest access. However, Chapter 7 demonstrated that for men, and those without qualifications in particular, improved forest access between time points was associated with reduced risk of long-term illness, compared to those whose forest access did not change. Forest use partially explained the relationship between forest access and general health but a direct effect of forest proximity on health was still present. Lastly, evidence suggested that better forest access across the life course, and at particular time periods, may be linked to reduced inequalities in mental health later in life between men and women and between those with higher and lower socioeconomic status.

This final chapter discusses these findings, drawing on the main bodies of empirical evidence regarding forests, green spaces and health and wider theoretical perspectives including socioecological models of health and the environmental justice framework. The strengths and limitations of the thesis are then discussed, followed by suggestions for future research in the field and implications of this piece of research for policy. Lastly, the thesis concludes by summarising the main contributions to knowledge.

8.2 **Changes in forest access and environmental justice**

8.2.1 Overall changes in forest access

Firstly, findings showed that the total forest area (ha) in Scotland had increased substantially throughout the study period and that overall access had improved, particularly between 1991 and 2001. The increase in forest area identified is reflective of the rapid growth of forest planting from the end of World War Two, to the end of the 20th century. As discussed in Chapter 2, an intense period of forest planting (in both private and public sectors) followed World War Two to replenish the timber resources lost and address unreliability of imports during this time. The rapid growth of the forest industry was supported by generous tax incentives, absence of environmental regulation and technological advancements in forestry machinery.

At the start of the study period, the best access to forests was in the Grampian and South Scotland regions which mainly consist of rural settlements with low populations. These areas are characterised by high ground (at least 200-500m above sea level), mountainous landscapes and lower average air temperatures compared to the rest of Scotland (Met Office

2016). This geographical pattern is reflective of the Government's post-war policy of concentrating forestry in upland Scotland, where conditions were unsuitable for growing crops (Foot, 2003). Between 2001 and 2011, the trend had shifted, with Central Scotland having the best access to forests at both time points. Again, the findings correspond to the political and social changes taking place in the forestry industry from the 1970s onwards. These included the introduction of new environmental legislation which restricted some forestry operations, increasing public concerns about the ecological and aesthetic impact of large monoculture woods on the landscape, growing positive attitudes towards biodiverse forest environments and awareness of the potential social and health benefits of forestry. The shift from 'industrial' to 'post-industrial' forestry around the 1980s and 90s whereby forests were now expected to provide a wide range of benefits for people and the environment in order for public financial support to be granted, could explain these findings. Additionally, the broadening of funding sources to charities aimed at delivering social outcomes, such as enhancing quality of life for communities, meant that the planting and maintenance of smaller recreational forests, closer to larger populations, could now be supported (Foot, 2003). Changes to structural factors, including availability of public funding and social attitudes towards forestry, are likely to have contributed to geographical patterns of forest access across Scotland. However, the results of the analysis showed that there were socioeconomic as well as spatial inequalities in access to forests throughout the study period. As suggested in previous literature, it is possible that processes of environmental injustice may have contributed to the continuation of these inequalities.

8.2.2 Socioeconomic inequalities in forest access

Socioeconomic inequalities in forest access were demonstrated throughout the study period between areas and between individuals. The results showed that the most deprived areas of Scotland had the worst forest access at each of the three time points, compared to more affluent areas. Furthermore, when forest access trajectories of individuals were modelled, findings demonstrated that those with lower socioeconomic status (social renters) were significantly more likely to have worse access to forests throughout the study period, than those with higher socioeconomic status (home owners). Such findings make a novel addition to the current literature on socioeconomic inequalities in access to health-promoting environments, which has tended to be reliant on cross-sectional analyses. Until now, knowledge about how socially uneven patterns of access may have developed over time, and identification of possible contributing factors e.g. structural change, has been limited. Inequalities in forest access may be due to a number of structural factors reflecting distributional and procedural injustice. As described above, in the decades following World War Two, large-scale forestry was, by instruction from the UK Government, located to the Scottish uplands for timber production, where a large proportion of the land was (and still is) owned by a relatively small number of affluent individuals. In 1995, 50% of Scotland's private land was owned by 421 people; by 2012 this had only marginally increased to 432 (Scottish Government 2015a). Also, in 2016 it was estimated that only 3% of the 20% most deprived areas of Scotland are located in remote rural areas (Scottish Government 2017). By contrast, the most deprived neighbourhoods of Scotland are concentrated in densely populated urban areas, the majority of which are distributed along Scotland's Central Belt. Historically, this region has been characterised by heavy industries such as coal-mining, ship building, steel and iron works and manufacturing (Tomlinson & Gibbs 2016). The decline of those industries resulted in high unemployment, among males in particular, across the area. Results of the 1991 census showed that Glasgow City, Inverclyde and the Cumnock & Doon Valley district were the worst affected, where in at least 20% of census output areas, 1 in 3 males were unemployed (Pacione 1995). Socioeconomic inequalities in access to forests may be explained by the spatial concentration of deprivation in the urban areas of the Central Belt, and the locating of early, large-scale forestry developments in the wealthy and more remote rural Scottish Uplands.

In addition to the role of structural and economic factors in shaping Scotland's forest distribution, it is also possible that processes of procedural environmental injustice may have contributed to socially uneven patterns of forest access. Decision making in the 'industrial forestry period' (1945-1980) was confined to private land owners, farmers, high earners and high tax payers, who were exclusively favoured by the Government's unregulated financial support and targeting of commercial forestry development to rural areas (Mather 1987). It was also suggested that residents and community groups were not consulted about the forestry operations that were planned for their local area (Foot, 2003). Processes of procedural injustice with regards to forest access have also been identified elsewhere in the UK and US. For example, one qualitative study based in the South Wales valleys highlights insufficient communication and sharing of information between Forestry Commission Wales and local communities when urban forestry developments were being planned in the early 2000's. When speaking of the forestry operations, local residents stated that *"they weren't told it was going to happen or why it was happening*" (Kitchen, 2013, pg.1976) and that, although consultations took place, members of the local community perceived them to be 'at a distance' and felt that they were not encouraged to attend (Kitchen 2013). In the US, it has been suggested that environmental decision-making regarding outdoor recreational environments has largely been restricted to a group of 'traditional stakeholders and representatives' that serves the interests of white middle class communities and excludes the views of less affluent and ethnic minority groups (Floyd et al. 2002). Closely linked to procedural injustice is the 'capabilities' perspective of environmental justice, placing emphasis on the opportunities individuals have to improve their quality of life, which may also help explain socioeconomic inequalities in people's forest access (Nussbaum 2003). For example, emphasised in the capabilities approach is having a sense of *"control over one's environment"* (Nussbaum, 2003 pg.42) and being able to participate in political procedures which, evidence suggests, are often not available to those on low incomes. Studies in the UK have demonstrated that individuals with low socioeconomic status, particularly social renters, have limited choice on where to live (Tunstall et al. 2013) and are less likely to participate in community groups (Gordon et al. 2000). Studies in Canada and the US have shown that residents' associations in more affluent areas, with higher proportions of home owners and individuals with higher income, were more actively involved in the management of urban forests and community-based environmental science projects than areas with lower proportions of home owners and those with lower incomes (Conway et al. 2011; Foster & Dunham 2015). Therefore, as has been the case elsewhere, it is possible that inequalities in forest access could be partly reflecting procedural environmental injustice whereby disadvantaged communities and individuals were excluded from processes of decision-making regarding forestry during the early, 'industrial' phase of forest expansion (1945-1980s). Whilst the findings of the current study and the work of others may suggest this, qualitative research into the policies and practices throughout this period would provide further insight into whether processes of procedural environmental injustice were in operation.

Whereas Scotland's urban deprived areas continued to have relatively poor access to forests throughout the study period, findings nonetheless indicated that they experienced the greatest improvements in forest access and that socioeconomic inequalities in forest access between deprived and affluent areas reduced between the three time points. These findings may partly be due to the shifts in forest policies described above, whereby planting of recreational forests in populated areas was now actively supported (post 1980s). As described in Chapter 1, a particularly prominent new funding opportunity offered late in the period covered by this longitudinal study was the Woods In and Around Towns (WIAT) programme. This was launched in 2006 and aimed to improve forest access for people living in urban areas, particularly those in the most deprived areas. An evaluation of the programme suggested that such woodland enhancements in urban neighbourhoods delivered important health and social benefits to people living there.

8.3 **Associations between forests and health outcomes**

The main results from Chapters 5-7 discussed below are summarised in Tables 8.1-8.3 respectively. These indicate which health outcomes were found to be significantly related to forest proximity measures.

	Bad general health 2011	Long-term limiting illness 2011	Mental health condition 2011	Prescribed antidepressants 2011-2016	Mental health outpatient 2011-2016
Distance to the nearest forest 2011 (m) (reference: 0-<150m)					
150-<300	✓	✓			
300-<500	✓	✓			
500-<750	✓	✓			
750-<1500	✓	✓			
>=1500					
Distance to the nearest accessible forest 2011 (m) (reference: 0-<150m)					
150-<300	✓				
300-<500	✓	✓			
500-<750	✓	✓	✓		
750-<1500	✓	✓			
>=1500	✓	✓			
Trajectory groups – All forests (reference: Trajectory group 3 - Improvement to >=500m)					
1 – No change from 300-<500m	x	x			
2 – Improvement to <150m	x	x		x	
Trajectory groups – Accessible forests only (reference: Trajectory group 4 - Improvement to >=500m)					
1 – No change from 300-<500m	x	x			
2 – Improvement to <150m	x	x	x	x	
3 – No change from >=1500m				x	

Table 8.1: Summary of significant findings from fully adjusted binary logistic regression models tested in Chapter 5 (controlling for sex, age group, ethnicity, children in the household, highest-level education, housing tenure, urban-rural classification and distance to the coastline (km)), n=97,658. Source: Scottish Longitudinal Study.

✓ = Significant positive association
x = Significant negative association

Cohort (Age in 1991)	All forests				Accessible forests only			
	Prescribed antidepressants 2011-2016		**Mental health outpatient 2011-2016**		**Prescribed antidepressants 2011-2016**		**Mental health outpatient 2011-2016**	
Cohort 1 (18-29)	**Critical time period 2001** **(reference: 300-<750m)** 0-<300m >=750m		**Critical time period 2011** **(reference: 300-<750m)** 0-<300m >=750m		**Critical time period 2011** **(reference: 300-<750m)** 0-<300m >=750m		**Critical time period 2011** **(reference: 300-<750m)** 0-<300m >=750m	
Cohort 2 (30-44)	**Effect modification 1991-2001** **(reference: 300-<750m)** 1991 0-<300m 1991 >=750m 2001 0-<300m 2001 >=750m 1991 0-<300m x 2001 0-<300m 1991 0-<300m x 2001 >=750m 1991 >=750m x 2001 0-<300m 1991 >=750m x 2001 >=750m	 x	**Accumulation (strict)**		None selected		**Accumulation (strict)**	
Cohort 3 (45+)	**Accumulation (strict)**		**Accumulation (strict)**	✓	**Critical time period 2001** **(reference: 300-<750m)** 0-<300m >=750m		**Accumulation (strict)**	✓

Table 8.2: Summary of significant findings from fully adjusted binary logistic regression models (life course model specifications) tested in Chapter 6 (controlling for sex, children in the household, highest-level education, housing tenure, urban-rural classification distance to the coastline (km) and whether the SLS member had the outcome of interest previous to 2011), n=97,658. Source: Scottish Longitudinal Study.

✓ = Significant positive association
x = Significant negative association

	Long-term limiting illness
Distance to the nearest forest (m) (reference: >=1500)	
0-<150	x
150-<300	
300-<500	
500-<750	
750-<1500	
Within-person component of change over time	
Between-person component of change over time	✓
Distance to the nearest accessible forest (m) (reference: >=1500)	
0-<150	x
150-<300	x
300-<500	
500-<750	
750-<1500	
Within-person component of change over time	
Between-person component of change over time	✓

Table 8.3: Summary of significant findings from fully adjusted random effects and hybrid effects models (deconstructing the within-person and between-person components of change over time) tested in Chapter 7 (controlling for sex, children in the household, highest-level education, housing tenure, urban-rural classification distance to the coastline (km) and whether the SLS member had the outcome of interest previous to 2011), n=97,658. Source: Scottish Longitudinal Study.

✓ = Significant positive association
x = Significant negative association

8.3.1 Forest access trajectories and health at the end of the study period

Findings on forest access trajectories and health (from Chapter 5) are summarised in Table 8.1. Results indicated that people with better forest access trajectories over the study period (i.e. those who remained 300-500m from the nearest forest over the three time points; or improved forest access and lived <150m from the nearest forest in 2001 and 2011) were less likely to report a long-term illness or poor general health at the end of the study period than those in the worst forest access trajectory group. Although there is no directly comparable literature, these findings are consistent with some but not all studies of green space and health. There are some cross-sectional studies in European countries, including the UK, which support a positive relationship between green space and self-reported general health and life satisfaction for the general population (Dadvand et al. 2016; de Vries et al. 2003; Maas et al. 2006; Mitchell & Popham 2008; Roe et al. 2016). However, not all studies have found this relationship (Akpinar 2016; Richardson & Mitchell 2010).

As an alternative approach, drawing on broader theoretical perspectives of place and health may provide useful insight into why people with better forest access trajectories had better general health at the end of the study period. One explanation might be that access to forests has a protective effect which develops through long-term exposure and is important for general health later in life. As suggested by socioecological models of health, environments can be salutogenic in encouraging or supporting certain healthy behaviours (Beute & de Kort 2014). For example, having better access to forests may encourage people to be more physically active (Pietilä et al. 2015). Also, spending more time outdoors may be linked to more social encounters with neighbours (O'Brien et al. 2014) which has been shown to be related to better well-being (Kawachi & Berkman 2001). It is possible that having better access to forests for long time periods (10-20 years) indirectly supports general health later in individuals' lives because of the continued opportunities for healthy behaviours. It may also be the case that prolonged periods of good access to forests allows sufficient time for positive perceptions of forests to develop, which may lead to greater use of forests for physical activity. Studies which have explored health outcomes of people's trajectories of neighbourhood poverty in the US have also suggested longer time frames for mechanisms (Murray et al. 2010; Sheehan et al. 2017).It has been suggested that the pathways connecting neighbourhoods to obesity e.g. limited availability of healthy food, can take decades to develop before having significant effects on health behaviours and health outcomes (Sheehan et al., 2017).

Those whose forest access improved and who lived in immediate proximity to the nearest forest (<150m) in 2001 and 2011 were also less likely to have been prescribed antidepressants between 2011 and 2016. This finding adds to the existing evidence about relationships between forests and reduced symptoms of depression and other mental illnesses (Iwata et al., 2016). This evidence has mainly relied on cross-sectional studies involving the collection of self-reported measures for small samples of individuals. Quasi-experimental and qualitative studies have suggested that forests may enhance mood by providing a sense of escapism from everyday life, reducing stress, promoting relaxation and increasing positive thoughts (Bielinis et al. 2018; Tsunetsugu et al. 2010; Ulrich, 1983; Ward Thompson et al., 2005). In addition to empirical work, Attention Restoration Theory (ART) also proposes that natural environments may promote mental health by supporting the recovery of mental fatigue (Kaplan & Kaplan 1989) which increases capacity to cope with challenging or stressful situations – a factor associated with resilience against mental illnesses such as depression (Southwick & Charney 2012). Thus, one explanation might be that having long-term good access to forests and increased use of forests helps to build up resilience and protection against more severe forms of depression (through mental restoration, increased positive thoughts, reduced stress etc.), which may reduce the need for antidepressant medication (normally only prescribed in cases where depression is 'moderate' or 'major' (NHS 2016)). Both sets of pathways, linking forest access trajectories to better general health and reduced likelihood of being prescribed antidepressants, are summarised in Fig.8.1

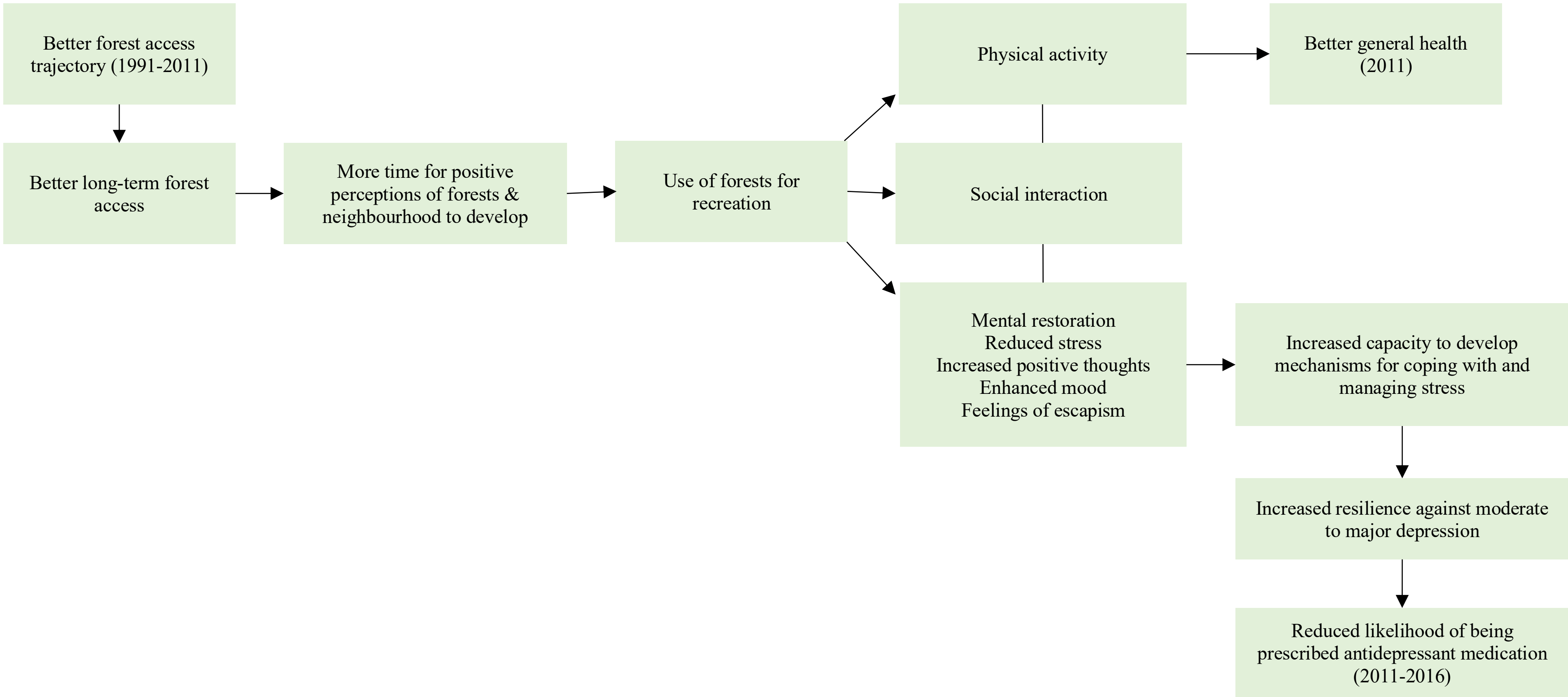


Fig 8.1: Potential development of pathways through time linking better forest access trajectories to better general health in 2011 and reduced likelihood of being prescribed antidepressants in 2011-2016.

8.3.2 Changes in forest access and health between time points

The results of Chapter 7 provided insights into the relationship between forests and long-term illness. In this section, changes within individuals between time points were explored and it was found, using a hybrid-effects model, that for the whole sample, individuals did not have significantly better health at the time points when they had better forest access. This contrasts with a previous study which used a similar approach to examining associations between green space and health in England using longitudinal data (White et al. 2013b). Results of the earlier study showed that people were less distressed and reported higher levels of life satisfaction when living in urban areas with more green space, compared to living in urban areas with less green space. Another longitudinal study in England has shown that individuals experienced sustained improvements in mental health in the years after moving to greener areas (Alcock et al. 2015). Both of these studies used a sample of individuals from the British Household Panel Survey (BHPS) which has several advantages for exploring associations between changes in exposures and changes in outcomes over the SLS. Firstly, the BHPS contains more frequent waves of data than the SLS, which allows more time points for within-person variability to be identified. Secondly, having more frequent waves of data allows better assessment of whether improvements in health followed, rather than accompanied, improvements in green space access. However, unlike the SLS and linked administrative health data used in this study, the BHPS contains only self-reported outcomes measures of health which are prone to bias.

A limitation of this part of the thesis was that data relating to forest access and health were only available for contemporaneous time points and there was no information about the SLS members' level of forest access or general health between the three study time points. Such information would have allowed the temporal ordering of events to be better established e.g. whether an individual's health improved one or two years after forest access had improved. As suggested in Section 8.3.1, the mechanisms through which forests are thought to be related to health may take time to emerge and depend on positive perceptions about forests developing first i.e. a longer latency period. Under this assumption, changes in an individual's health would not be expected to take place in the same year as forest access was improved, as it might be too soon for changes in behaviour (e.g. increased physical activity), firstly, to occur and, secondly, to have a measurable impact on health outcomes (e.g. reduced Body Mass Index). Since this study took place, NHS GP registration data consisting of postcodes and dates of each new registration since January 2000 has been linked to the SLS. With this new data available, future research could examine the associations between continuous changes in forest access from 2000 and changes in health.

8.3.3 Differences between males and females

Throughout the empirical analyses, differences in the associations between forests and health were identified between men and women. In Chapter 6, although findings (as summarised in Table 8.2) were not consistent across cohorts, some results suggested that life course models of forest access may only have protective effects on later mental health for women. For women aged 45+ in 1991, the accumulation of forest access across the study period was associated with reduced risk of being a mental health outpatient in 2011-2016. There was also an indication that accumulation of better access to forests, and access at particular time points, may have roles in reducing later inequalities in mental health between men and women by improving women's mental health. Similarly, previous studies (not specifically on forests) have found that access to green spaces supported the mental health of women (van den Bosch et al. 2015) and that women with worse green space access had higher stress levels (Roe et al. 2013). A possible reason for why women's mental health might benefit more from forest access could be that women are more likely to spend more time at home during the day than men, e.g. for caring responsibilities and working part-time (Scottish Government 2016). Therefore, women may use forests for physical activity and socialising more so than men. However, other work on green space has suggested that green spaces support mental health of men but not women (Astell-Burt, Mitchell, et al. 2014). It has also been suggested that women may be less likely to visit forests regularly (Ward Thompson et al. 2005), possibly due to concerns about personal safety (Krenichyn 2006; Morris et al. 2011; O'Brien et al. 2005). However, as demonstrated in previous studies, it is possible for people to benefit from having good access to forests without necessarily visiting them, e.g. benefitting from the stress reducing effects of viewing forests in comparison to built or urban environments (Van den Berg et al. 2014). Family circumstances and other sociodemographic characteristics such as life stage are also thought to influence women's perceptions and use of outdoor environments, more so than men's (Richardson & Mitchell, 2010). Other factors may offer reasons as to why associations were more prominent in the oldest cohort (discussed further in Section 8.3.4). One possible explanation might be that women in this cohort (aged 45+ in 1991) were more likely to follow traditional gender roles than women in younger cohorts. This can be illustrated by the increase in proportion of women in the labour market from 53% in 1971 to 67% in 2011 (Jenkins 2013). Therefore, women in the oldest cohort may have spent more time in the home and neighbourhood environment in the decades leading up to and included in the study period, than men. As suggested above, it could be that women who had more exposure to forests in earlier life (through viewing or visiting forests) have accumulated coping mechanisms (through restorative and stress reducing effects of forests) which then help to protect against future mental illnesses.

Differences between males and females were also found in Chapter 7 which investigated whether people's general health was better when they lived closer to forests. Unlike the results of Chapter 6, this analysis demonstrated that forest access may be of more benefit to men's general health rather than women's general health. Most notably, men whose access to publicly accessible forests improved over time had significantly lower odds of long-term illness than men who remained furthest from forests. For men only, there was a distinct trend in the effect size, the magnitude of which increased as distance to the nearest forest decreased, indicating that those whose forest access improved the most gained the greatest benefit. There have been no studies which investigated links between forest access and risk of illness specifically for men; but studies from the green space literature provides some insights. It has been shown in a UK study that areas with more green space had lower rates of mortality relating to cardiovascular and respiratory conditions among men only (Richardson & Mitchell 2010). Studies in the UK and US have shown that men were significantly more likely to use green spaces for physical activity than women (Cohen et al. 2007; Miller et al. 2014; TNS 2014b) however the opposite was found in a Canadian city, where more positive associations were found between availability of green space and physical activity among women than among men (Kaczynski et al. 2009). Also, qualitative findings from previous studies suggest women have concerns about personal safety which deter them from visiting forests (Krenichyn 2006; Morris et al. 2011; O'Brien et al. 2005). Taking these points into consideration, one explanation why improvements in forest access may benefit men's general health, and not women's, might be that the mechanisms through which forests are related to general health e.g. increased physical activity, emerge more quickly in men. This could be due to men having fewer reservations and concerns about personal safety and, as a result, being more likely to feel comfortable whilst visiting forests recreationally and therefore more likely to gain any associated health benefits comparatively quickly.

8.3.4 Differences between cohorts

As suggested above, the findings in Chapter 6 demonstrated that associations between forests and mental health through time were only significant for the oldest cohort in the sample (aged 45+ in 1991). Previous cross-sectional studies have also demonstrated that forests may benefit middle-aged and older people in particular by reducing stress and improving mood (Horiuchi et al. 2013; Sawa et al. 2011; Shin et al. 2012). However, it is difficult to explain the results of the current study without further research. One possibility might be that those in this cohort were more likely to have previous experiences and memories of visiting and viewing forests than younger generations. Earlier studies have demonstrated that memories and experiences of forests and green spaces, particularly those in childhood, are significant factors in determining use of forests for recreation in later life (Bell & Ward Thompson 2014; Evered 2016; Ward Thompson et al. 2008; Ward Thompson et al. 2005). Also, it has been noted that younger generations spent less time outdoors in childhood compared to earlier generations due to growing parental fears about children playing in public spaces unsupervised (Carter & O'Brien 2008) and increasing use of technology-based entertainment e.g. televisions (Greenfield 1984). It could be the case that older individuals in the sample spent more time in natural environments as children, partly due to having fewer indoor activities available to them. Also, there may have been fewer restrictions on outdoor activities and access to forests than for younger generations e.g. due to parental fears, increasing urbanisation and busy roads. Older cohorts may feel more comfortable and get more enjoyment from visiting forests for recreation as older adults and, therefore, may be more likely to gain mental health benefits e.g. mental restoration, reduced stress. On the other hand, younger cohorts may have spent less time in forests and have less appreciation for good access to forests as there were a greater range of alternative indoor and technology-based activities for leisure available to them as children and younger adults.

8.3.5 Differences between socioeconomic groups

There were significant differences in how associations between forests and health varied between socioeconomic groups when considering individual, rather than area-level measures of socioeconomic status. More positive associations between improved forest access and general health existed for those without qualifications. For this group only, those who had improved forest access from living >=1500m from the nearest forest to living <500m, had reduced risk of long-term illness, compared to those who remained living furthest from forests. A second example was identified in Chapter 6 as socioeconomic inequalities in the prescribing of antidepressants in 2011-2016 were narrower for those aged 45+ in 1991, with better cumulative forest access.

Stronger associations between access to green spaces (including forests) and general and mental health outcomes have been found for individuals with lower levels of education elsewhere in European cross-sectional studies (Dadvand et al., 2014; De Vries et al., 2003; Maas et al., 2006). It has been suggested that those with lower socioeconomic status are more susceptible to changes in their surrounding environment. This is possibly due to their activities being more restricted to within the boundaries of their neighbourhood (De Vries et al., 2003), whereas individuals with higher socioeconomic status are more likely to have the social and financial means to access a range of recreational opportunities, including those further afield from their neighbourhood. A change in neighbourhood forest access might not impact on the latter group's behaviour if they already have opportunities to undertake regular recreational activity, which may include physical exercise and / or outdoor pursuits and are sufficiently supported by strong social capital. This explanation draws on the Capabilities Approach (Nussbaum, 2003) and suggests that people with higher socioeconomic status may have a fuller capabilities set and therefore already have the opportunities to enable them to live a healthy lifestyle and undertake activities they want to, where they choose. On the other hand, people who are more socially deprived are more likely to experience poor health outcomes and may lack the efficacy to improve their life circumstances, perhaps due to poor employment opportunities and other disadvantages (Curtis & Jones 1998). Limited finances and time may also make it harder to visit and benefit from recreational environments outside of the neighbourhood. Therefore, individuals with lower socioeconomic status may be more likely to feel the benefit of improved nearby forest access as it provides an opportunity to significantly add to their capabilities set and improve their quality of life. This may also provide some explanation to why green environments were found to be 'equigenic' in other research (Mitchell et al., 2015; Mitchell & Popham, 2008).

The finding that higher levels of cumulative forest access reduced socioeconomic inequalities in the prescribing of antidepressant medication at the end of the study period could also be related to those with lower socioeconomic status being more sensitive to levels of forest access in their neighbourhood, because they spend more time there. It is plausible that the mechanisms connecting forests to mental health, processes that develop and accumulate over time (as shown in Fig 8.1), are more accentuated among more deprived individuals. This result, in particular, also makes a significant contribution to the literature and strengthens the evidence that access to forests and other types of green space may have a role in reducing inequalities in mental health outcomes. So far, this has only been shown for green space collectively in cross-sectional studies using self-reported measures of mental health (Mitchell et al. 2015).

However, in this study associations between forests and general or mental health were not found to be stronger for those living in deprived areas nor was there evidence of forest access reducing socioeconomic health inequalities at the area-level. This contrasts the findings of other studies on green space in the UK, Europe and the US (Brown et al. 2016; Roe et al. 2013; Ward Thompson et al. 2012; Ward Thompson & Aspinall 2011). It may be that forests are more important for reducing socioeconomic inequalities between individuals than between areas. As suggested above forests may be important for enhancing capabilities for those with lower socioeconomic status and this may be regardless of whether they live in deprived or affluent areas.

8.4 **Strengths and limitations**

8.4.1 Strengths

The main strengths of this thesis are related to the use of nationally representative, longitudinal data on individuals, their health and socio-demographic characteristics at different time points. Furthermore, the thesis makes a novel contribution through the linkage of forest access measures derived from historical forest and land-use inventories, which were calculated for small postcode geographies. As data were available for three separate time points, analyses were able to identify associations between changes in forest access and changes in health; and the potential long-term effects of forest access on health later in life. Also, the creation and linkage of synthetic estimates has been able to provide insight into whether use of forests is necessary in order for people to gain the health benefits associated with forests. This aspect of the thesis also contributes to the literature by illustrating how synthetic estimates can be utilised in research exploring relationships between forests (and other natural environments) and health. As large-scale data sources tend not to contain information about people's use of forests, linking synthetic measures from another representative survey can provide some insight to the expected behaviour of individuals, based on sociodemographic characteristics. The method used to create the synthetic estimates is advantageous as it only requires the presence of three sociodemographic variables (ethnicity, age and housing tenure) which are commonly found in social surveys and unlikely to have large amounts of missing data. Therefore, it could potentially be applied to other data sets. The approach may also be extended to further explore the mechanisms through which forests are related to health, if variables on related behaviours are available e.g. time spent doing physical activity in a forest, etc.

The large sample has also allowed differences in the associations between forests and health between socio-demographic groups to be investigated. Being able to explore such questions has strengthened the evidence base, which has until now mainly consisted of cross-sectional studies and/or those with smaller samples of individuals. Additionally, the linkage of administrative health records, including the prescribing of mental health medicines and hospital admissions, to individuals from the longitudinal data set has added to the range of different health outcomes which have been investigated in the field, which has to date largely relied on self-reported measures of health. Broadening the diversity of evidence on health outcomes which are positively associated with forest access, and the provision of evidence derived from a longitudinal investigation, provides an important contribution not only to the academic literature but also for those in the public sector. This thesis may provide more robust evidence for policy makers to draw on when designing, and applying for public funding to enable, projects like *WIAT* and *NHS Forest* to continue.

8.4.2 Limitations

Limitations of the research include the use of Euclidean distance rather than network distance when deriving forest access measures. This was due to historical data on access routes suitable for network analysis in ArcGIS not being available for 1991 and 2001. As discussed in Chapter 2, studies have shown that the two methods can produce different results and suggests that network analyses may produce more accurate measures of people's access (Higgs et al. 2012). However, studies also suggest that such approaches may be limited and not necessarily better than Euclidean measurements as they also do not take into account people's preferences in terms of routes such as choosing safer, less hilly or more aesthetically pleasing routes than the most spatially direct (Ikeda et al. 2018). It may also be argued that network distances are less relevant in this thesis as not all mechanisms associated with forests required individuals to visit the forest in order to benefit health e.g. forests may reduce stress through having a view. Where possible, it is still recommended that researchers interested in measuring access to forests and other health promoting environments conduct sensitivity analyses which compare results produced by both Euclidean and Network measures of access in addition to considering the potential theoretical pathways (Gascon et al. 2015).

The main exposure measures used were based on level of forest proximity which was estimated using the centroid of the SLS members' postcode for place of residence. Therefore, actual forest proximity for individuals is likely to vary depending on postcode area size. Also, it is plausible that environmental exposures elsewhere such as at the work place and school, influence health outcomes. Although the SLS contains postcodes for people's places of work, these were not available for each of the three census years at the time this study was carried out.

The measure of socioeconomic status used was highest-level educational qualification which did not allow for variation between those with different types of 'non-degree' qualifications. Due to the lack of detail in this variable and the absence of a measure of income, it is therefore possible that other sources of socioeconomic confounding may still be present in the analyses.

The Carstairs index was used as the measure of area-level deprivation which has been criticised for several reasons relating to the component measures used to create the index. However, this was the only area-level deprivation measure available for each of the three time points used in the study. Some of the approaches in the analysis may have off-set the problems associated with the index. For example, urban-rural classification and other measures of socioeconomic status were controlled for in the analysis, which may to some extent address the criticisms that the Carstairs index does not capture material deprivation in rural areas (Farmer et al. 2001) and that it includes indicators which are no longer relevant to deprivation e.g. overcrowding (Brown et al. 2014).

The measures used to capture aspects of mental health had some limitations. Firstly, the Prescribing Information System (PIS) did not contain information on the individual's diagnosis, meaning the data could not be used as a definitive indicator of depression. As described in Chapter 3, antidepressants may also be prescribed, particularly at low doses, to treat conditions other than depression. However, in the sensitivity analysis, the reclassifying of those on low doses did not change the results of the bivariate analysis in Chapter 5.

The health measures derived from the Census were self-reported. It is possible that there may be error in the responses due to 'social desirability bias' (Bowling 2005), particularly due to undercounting those with a mental health condition. People may have felt reluctant to report that they had a mental health condition due to stigma. However, the thesis has also involved the use of administrative health data which may be considered a less subjective way of measuring health. Despite this, it is still possible that factors such as stigma, lack of access to health services and lack of social support may have prevented people from seeking healthcare for a mental health issue.

The research explored the relationship between forest access and several different health outcomes, investigates potential differences in associations by socio-demographic groups and assesses the same health outcome at different time points. Therefore, it was possible that problems of multiple testing or 'multiplicity' may have arisen. These are common issues in epidemiological research and clinical trials whereby the risk of a false significant result, known as a 'Type 1 error', is inflated due to the volume of statistical tests being conducted within the overarching study aim or "family-wise hypothesis" being explored (Li et al., 2017). Several approaches to handling this issue have been proposed – the simplest and most commonly applied technique is the Bonferroni adjustment method which produces more conservative p-values thus adjusting the likelihood of a significant test result (Bender and Lange, 2001).

Decisions of whether or not to control for multiple testing errors are contested. It has been recommended that multiple testing procedures should be considered in studies which involve multiple outcomes, repeated measures and subgroup comparisons. However as aspects of study design help to reduce the risk of Type 1 errors (Li et al., 2017), there was less need to adjust analyses for multiplicity in this thesis. For example, statistical analyses plans and hypotheses were pre-defined and informed by a wide literature base; various sensitivity analyses were conducted, particularly at the initial stages of each section of analyses; and as the study is the first longitudinal investigation into associations between forests and health, it's conclusions cannot be considered 'confirmatory'. More so, there are arguments against adjustment for multiplicity. For example, by reducing the risk of Type 1 errors, the risk of Type 2 errors i.e. the chance that a significant result is not detected, is inevitably increased. Also, adjustment leads to the interpretation of each test depending on the number of outcome measures or social stratifications being analysed within the "family-wise hypothesis" – a concept which is ill-defined and has uncertain boundaries e.g. it is unclear whether we should be adjusting for multiplicity within individual studies or across studies by the same researcher or which explore comparable aims (Feise et al., 2002). Furthermore, approaches for handling multiplicity in longitudinal studies are rarely applied. Due to the complexity of the analyses i.e. between-individual and within-individual comparisons being conducted simultaneously, it has been difficult to develop appropriate adjustment methods (Bender & Lange, 2001). Therefore, as features of the study design reduced the need for adjustment due to the lack of validated methods that could be applied to longitudinal research, it was decided not to adjust for multiplicity in this study. However, it is acknowledged that there remains a slight risk of the analysis containing Type 1 errors.

In Chapter 7, it was found that, whilst use of forests partially explained the relationship between forest access and long-term illness, a direct effect was also present. Conclusions that can be drawn from this finding are limited as the analysis used synthetic estimates and not actual measures of the SLS members' use of forests. However it may illustrate that people benefit from living in areas with good access to forests through both direct (e.g. better air quality and stress reducing effects of viewing forests) and indirect (e.g. providing opportunities for physical activity and social interaction) mechanisms and that health benefits may be gained independent of whether or not people are actually using the forest.

The approach used to calculate the synthetic estimate also had some limitations. Firstly, the final SPANS sample used to create the estimates was relatively small (n=4,609) compared to the SLS and not all potentially important predictors of forest use, e.g. dog ownership, perceptions about forests, previous experiences in forests, etc. could be taken into account due to the data not being available in both SPANS and SLS. Although sensitivity analyses were carried out in order to validate the synthetic estimates, estimates may be biased due to missing observations for the predictor variables (2%). Finally, in this case, the synthetic estimates have been used to explore how forest use might explain the relationship between forest access and long-term illness through possible mechanisms such as physical activity and social interaction. However, it is possible that the links between forest use and other types of health outcome might be different to those associated with self-reported long-term illness. Therefore, in future applications of the synthetic estimates, it would be important to carefully consider the theoretical pathways through which forest use may be related to the outcome of interest. Also, the method used to test whether use of forests mediated the relationship between forest access and general health (Baron & Kenny 1986) has limitations. The main criticism of the 'Baron & Kenny' approach is that the specific conditions needed for identifying mediating effects are not made explicit, therefore assumptions are likely to be violated (Nandi & VanderWeele, 2017). In particular, any unmeasured confounding between the mediator and outcome may bias results (Emsley et al. 2010; Nandi & VanderWeele 2017). However, more sophisticated approaches have since been developed, including the 'causal inference' method (Robins & Greenland 1992). This more formal approach clarifies the conditions required for detecting direct and indirect effects; allows the testing of unmeasured confounding; allows for interactions between the exposure and mediator and can robustly estimate effects in non-linear situations (Emsley et al. 2010; Nandi & VanderWeele 2017; VanderWeele 2015). Therefore, future research into potential mediators of the relationship between forests and health should consider applying this approach.

Qualitative data and small experimental studies are also perhaps more suited to provide significant insight into people's connections with, and their use of, forests and the mechanisms through which forests may be related to specific health outcomes. Examples include the emotional benefits of social interaction in forests reported by people with depression (Townsend 2006) and evidence that forests may be important settings for physical activity, particularly for certain sociodemographic groups e.g. older people (O'Brien & Snowdon 2007) and those living in low-income households (O'Brien & Morris 2009b; O'Brien & Morris 2009a). However, such studies are unable to explicitly test which mechanisms are explaining the link between engaging with forests and health. This is due to these studies having small sample sizes and limited quantitative data on which to apply statistical techniques. Larger quantitative data sets with actual indicators of people's behaviours are still required in order to advance knowledge on mechanisms.

Data about levels of forest access during the SLS members' childhood were not available meaning forest access across the full life course and associations with health could not be assessed. Previous studies have highlighted the importance of childhood experiences of forests and memories of forests as a child in shaping connections with forests as adults (Bell and Ward Thompson 2014; Evered, 2016; Ward Thompson et al. 2005), as discussed in section 8.3.4. Furthermore, evidence indicates that green space access in childhood is pertinent for mental health in later life (Pearce et al. 2018). It is thus a possibility that any critical periods or cumulative effects of forest access on later health originally stem from experiences in childhood rather than earlier in adulthood. Where data are available, future research should consider the effect of forest access in childhood as well as adulthood on later health outcomes, using life course approaches. Further recommendations for future research are now discussed.

8.5 Future directions

The findings of this thesis provide a number of possibilities for future directions in work relating to forests and health but also identifies wider issues for research in health geography. Firstly, future research may seek to understand the ways in which nature may support health for those with specific mental illnesses. It was found that forest access was associated with some but not all of the health outcomes tested in the initial cross-sectional analysis, which focused on the 2011 time point only. Notably, forest access was found to be related to the prescribing of antidepressants and attending a mental health outpatient clinic; but not the prescribing of anxiolytics or being admitted as a mental health inpatient. It is possible that being a mental health inpatient indicates severe mental illness which has developed over a long period of time and is multifaceted. It has been suggested that serious mental illnesses result from psycho and social elements in childhood (Schmidt 2007). It could be the case that, whilst forest access may relieve some of the symptoms of mental health conditions (as identified in previous studies), it cannot prevent people from having serious mental illnesses. It could also be the case that those admitted to hospital for a mental health condition are not able to access nearby forests due to their health condition restricting their activities. There is also the possibility that the mechanisms through which forests are related to health are more relevant to providing relief from particular mental health conditions but not others e.g. depression and not anxiety. Further attention should be paid to the differences in symptoms, treatments and experiences of different mental health conditions when considering the possible therapeutic effects of forests.

Results suggested that relationships between natural environments, health and inequalities are different for island communities compared to those on the mainland as it was found that removing island postcodes from the analyses reduced inequalities in forest access between deprived and affluent areas across Scotland. The 2011 census has also indicated that island populations tend to be older, healthier and working in part-time or self-employed, non-professional roles. Furthermore, many of the islands did not have forests, therefore the concept of 'access' to forests and other natural environments is likely to be different for islanders. For example, the nearest forest for an island resident may be as far as the mainland or a neighbouring island. Researchers should consider the ways in which links between salutogenic environments, health and inequalities might vary between mainland and island populations. Furthermore, qualitative work may help provide insight to how perceptions and experiences of nature and access to nature might be different for those living on islands.

The study also brings to attention wider issues for the field of health geography. These include the implementation of longitudinal and life approaches to understand how places influence health through time. As illustrated in this study, considering people's movements between places throughout life and the histories of places themselves helps improve our understanding about potential links between environment and health e.g. whether environmental exposures influence later health cumulatively or through critical periods. Future research in this field may also consider the structural, spatial and temporal implications of public health interventions. It has been demonstrated that the distribution of forests in Scotland may largely have been shaped by structural, political, cultural and historical processes which are difficult to disentangle, and which have a role in maintaining the inequalities in forest access present at the end of the study period. Similarly, Rutter et al. (2017) suggest a shift towards 'complex systems approaches' is required in order to improve the current tactics employed in addressing public health challenges. Whereas longitudinal approaches are an improvement in the field exploring links between forests and health, complex systems approaches may provide further insight and assume that health outcomes are the results of many factors that are interdependent within and between different scales (B. Y. Lee et al. 2017). The degree to which one factor changes may influence the amount of change in another; and what works to improve health in one community or sociodemographic group, may not have the same effect elsewhere. Those interested in improving public health and reducing health inequalities through enhancing access to forests and other salutogenic environments may therefore also consider the ways in which structural-level factors interact with those operating at lower levels such as the characteristics of local authority areas, neighbourhoods, households and individuals, to encourage or hinder people's level of access to and use of forests.

8.6 **Policy implications**

The findings of the thesis have implications for the study sponsors: Forestry Commission Scotland (FCS) and the Scottish Government, others who are interested in the ways in which forests support people's health and those tasked with reducing health inequalities. The study has also been awarded a grant from the Scottish Graduate School of Social Science (SGSSS) to support research impact and knowledge exchange activities. These will include the production of an infographic and organisation of a seminar/workshop to which academic and policy- and community-orientated stakeholders will be invited e.g. FCS, NHS, Greenspace Scotland, Woodland Trust etc. This will enable sharing of results with key stakeholders and will facilitate further discussions of how the research findings may contribute to changes that would benefit peoples' health, reduce health inequalities and enhance quality of life. The results indicated that, although forest access had improved between the three time points for those living in deprived areas, individuals with low socioeconomic status were more likely to have worse forest access throughout the study period and less likely to have better forest access trajectories. Furthermore, those with better forest access trajectories were less likely to have worse general health, long term illness and be prescribed antidepressants. This suggests that FCS initiatives such as *WIAT*, which is currently targeted at deprived areas and uses the Scottish Index of Multiple Deprivation (SIMD) to identify those neighbourhoods, should also consider ways in which to target interventions at those with low individual-level socioeconomic status in order to reduce health inequalities. This may involve using the individual indicators contained within the SIMD or census information to identify where people with low socioeconomic status are concentrated e.g. number of working age people with no qualifications. Other data which could be potentially useful in targeting those with low socioeconomic status and which may be publicly available include locations of foodbanks and locations of current and future social housing estates. The thesis has shown how it is possible for Forestry Commission Scotland to potentially link their administrative records e.g. historical and current forestry inventories, to public health information in order to evaluate the success of interventions such as *WIAT* and the potential influence of woodland expansion on health at the population-level.

Of particular relevance to those interested in reducing health inequalities among genders are the distinct differences in the relationships between forests and health between males and females. Results indicated that improving forest access may be particularly beneficial to the general health of men and those without qualifications. There have been few studies which have focused on associations between forests and the health of males with low socioeconomic status in particular. Potentially, this is an important finding for policy, particularly in Scotland where the Government has previously prioritised improving men's health and reducing male health inequalities, for example through the Well Men's Services (WMS) policy initiative (Douglas et al. 2015). However, as discussed earlier, other studies suggest that women are less likely than men to use forests for recreation due to personal safety concerns. Despite these issues, differences between males and females have been largely neglected in the literature on health inequalities. Furthermore, some have argued that initiatives to reduce health inequalities have largely focused on differences in the health behaviours of men and women and have ignored the wider structural factors that have shaped disparities in mortality and morbidity rates between the sexes (Douglas et al. 2015; Scott-Samuel et al. 2015). Therefore it is recommended that future interventions involving the use of forests for enhanced health should consider potential gender issues and design interventions in such a way that they reflect differences in how men's and women's perceptions and interactions with forests are shaped. A starting point may include a detailed qualitative investigation e.g. conducting gender-specific focus groups, to better understand the particular barriers to using forests, how they develop and how they vary between different gender groups.

Lastly, those working towards improving access to forests and other health-promoting environments may wish to revisit predefined threshold distances which are considered beneficial for health. Whereas the policy literature states the important of living within 500m of an accessible forest, the academic literature suggested that potential thresholds varied according to the health outcome and sociodemographic groups being investigated. In this thesis, there were several examples of where individuals living less than 500m or 300m from the nearest forest had better health outcomes than those living furthest, but this was not consistent across the different health outcomes studied and questions being explored. For example, in the cross-sectional analysis, those who lived more than 150m (across five distance bands) to the nearest accessible forest were all more likely to have a long-term illness. There were also general health benefits associated with trajectories of greatly improved forest access (to living <150m from the nearest forest in 2001 and 2011) and for those who remained living between 300-500m throughout the study period. However mental health benefits were only identified for those with the former trajectory. Therefore, planners and those designing forest-based public health interventions should consider several different distance thresholds suggested in the academic literature when conceptualising forest access and be aware that those important for health may vary according to the particular health problem being targeted and other factors including the mobility levels of the target population. Furthermore, as better trajectories of forest access are linked to better health outcomes, policies ensuring the long-term maintenance and protection of publicly accessible forests in close reach of populations should be put in place to maximise the health and social benefits delivered.

8.7 Concluding remarks

This thesis was the first longitudinal study of associations between forests and health at the scale of the population. By linking GIS-based environmental, census and administrative health data and applying several different analytical approaches, the thesis has made an original contribution to the international field by providing new insights into the relationships between forest access and different aspects of general and mental health.

Furthermore, by mapping forests and forest access for Scotland's population at three different time points (which will be made available to other researchers), the thesis has identified differences in forest access between sociodemographic groups in the population and has explored disparities in health between these groups that may be considered outcomes of environmental injustice.

More broadly, the thesis has contributed to the wider field investigating environment, inequalities and population health by demonstrating the importance of having local access to salutogenic environments in supporting good health and mitigating ill health caused by noncommunicable diseases. Finally, the research has provided important evidence for policy makers, particularly about the value of forestry in Scotland (and potentially elsewhere) and the prospects to develop and manage forestry for the future wellbeing of the population.

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